TN 295
.U4

No. 8969

THE LIBRARY OF CONGRESS

THE LIBRARY OF CONGRESS

IC 8969

Bureau of Mines Information Circular/1984

LIBRARY OF CONGRESS
4
APR 25 1984
COPY
EXCHANGE & GIFT DIVISION

Gold and Silver Leaching Practices in the United States

By Peter G. Chamberlain and Michael G. Pojar

UNITED STATES DEPARTMENT OF THE INTERIOR

Information Circular 8969

Gold and Silver Leaching Practices in the United States

By Peter G. Chamberlain and Michael G. Pojar

UNITED STATES DEPARTMENT OF THE INTERIOR
William P. Clark, Secretary

BUREAU OF MINES
Robert C. Horton, Director

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. administration.

TN295
.U4
no.8969

Library of Congress Cataloging in Publication Data:

Chamberlain, Peter G., 1942-

Gold and silver leaching practices in the United States.

(Bureau of Mines information circular ; 8969)

Bibliography: p. 36-38.

Supt. of Docs. no.: I 28.27:8969.

1. Gold mines and mining—United States. 2. Silver mines and mining—United States. 3. Solution mining—United States. I. Pojar, Michael G. II. Title. III. Series: Information circular (United States. Bureau of Mines) ; 8969.

~~TN295.U4~~ [TN423.A5] 622s [622'.3422] 83-600316

For sale by the Superintendent of Documents, U.S. Government Printing Office
Washington, D.C. 20402

CONTENTS

	Page
Abstract	1
Introduction	2
Acknowledgments	4
Mineralogy	5
Leaching technology	6
Heap leaching ore preparation	6
Dump leaching ore preparation	7
In situ leaching ore preparation	7
Leaching process	8
Leach solutions	8
Solution distribution	8
Recovery	12
Comparison of techniques	12
Zinc precipitation	12
Charcoal adsorption	14
Leaching operations	15
Arizona	22
California	23
Colorado	23
Idaho	25
Montana	25
Nevada	26
New Mexico	28
South Dakota	29
Permitting regulations	29
Federal regulations	29
State regulations	30
Leaching problems and research	33
Percolation	33
Temperature	33
Solution loss	33
Calcium salt scale	34
Research on novel solution mining methods	34
In situ leaching	34
Leach farming	35
Thin-layer leaching	35
Summary	36
References	36
Appendix.--Gold and silver leaching bibiliography	39

ILLUSTRATIONS

1.	Heap leaching system	2
2.	Typical pilot heap leaching operation	3
3.	Dump leaching system	3
4.	In situ leaching systems	4
5.	Fixed-spray solution distribution	9
6.	Rainbird sprinkler	9
7.	Bagdad wiggler	10
8.	Solution distribution by ponding	11
9.	Pregnant effluent solution collecting pond	11

ILLUSTRATIONS--Continued

Page

10. Zinc precipitation recovery system..... 13
11. Charcoal adsorption recovery system..... 14
12. Leaching operation locations in the United States..... 22
13. In situ leaching test at Ajax Mine..... 24

TABLES

1. Gold and silver heap and dump leaching operations in the Western United States..... 16
2. Location data for key operations..... 19
3. Ore mineralization and process characteristics..... 20
4. Leach solution treatment..... 21
5. Environmental Protection Agency regional offices..... 30
6. State permitting agencies..... 31

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

A	ampere	L/s	liter per second
A/ft^2	ampere per square foot	$L/s \cdot cm^{-2}$	liter per second per square centimeter
Btu/h	British thermal unit per hour	m	meter
°C	degree Celsius	mi	mile
cm	centimeter	min	minute
ft	foot	m^2/kg	square meter per kilogram
ft^2/lb	square foot per pound	$mL/s \cdot cm^{-2}$	milliliter per second per square centimeter
g	gram	mm	millimeter
gal/min	gallon per minute	mol/mol	mole per mole
$gal/min \cdot ft^{-2}$	gallon per minute per square foot	oz	ounce
g/kg	gram per kilogram	oz/ton	ounce per ton
h	hour	Pa	pascal
in	inch	pct	percent
kg	kilogram	ton/d	ton per day
kg/d	kilogram per day	ton/yr	ton per year
kg/m^3	kilogram per cubic meter	V	volt
km	kilometer	W	watt
lb	pound	wk	week
lb/ft^3	pound per cubic foot	wt pct	weight percent
lb/in^2	pound per square inch	yr	year
lb/ton	pound per ton		

GOLD AND SILVER LEACHING PRACTICES IN THE UNITED STATES

By Peter G. Chamberlain[1] and Michael G. Pojar[2]

ABSTRACT

The surge in gold and silver prices during the 1970's attracted many new mining operators and has rekindled interest among experienced ones. With its low capital investment requirements and fast payout, leaching has attracted many operators--particularly those with small or low-grade deposits. Although in certain situations leaching offers many advantages over conventional mining methods, many operators are uncertain how these relatively new techniques should be implemented. Consequently the Bureau of Mines has prepared this circular to disseminate information on gold and silver leaching practices, techniques, and problems. Engineering data gathered from 26 operations indicate that most ores are leached in heaps following crushing and distribution on pads. Metal values are recovered from cyanide leach solutions using either zinc precipitation or charcoal adsorption. Potential problems that may hamper on block development of a leaching operation are poor percolation characteristics of the ore, calcium salt buildup, low temperatures, and solution losses. An extensive bibliography on gold and silver leaching is appended.

[1]Supervisory mining engineer.
[2]Mining engineer.
Twin Cities Research Center, Bureau of Mines, Minneapolis, MN.

INTRODUCTION

Climbing gold and silver prices during the 1970's awakened dormant interest in mining these metals in many districts. Since gold and silver deposits frequently can be profitably mined by small operators, a mix of mining activity has been created, comprised of large and small companies, both experienced and unexperienced. A key factor in the profitability of small mining operations is the advent of an alternative to conventional mining and milling operations--solution mining (leaching). Basically gold and silver leaching involves spraying a cyanide solution on the ore to dissolve the metal values, collecting the solution containing the dissolved metals, and recovering the metal from the solution. By eliminating milling, leaching reduces capital cost and startup time for new operations. Operating costs are likewise significantly lower. The disadvantages of leaching are lower recovery and greater difficulty in controlling the cyanidation process.

There are three types of leaching systems--heap, dump, and in situ; "vat" leaching accompanying conventional milling operations is not considered in this publication. If ore is mined or if it is gathered from old mine waste-rock piles and hauled to specially prepared pads lined with clay, tar, or Hypalon[3] for leaching, the method is "heap" leaching (figs. 1-2). The rock is frequently crushed before being placed on the pad.

If mine waste-rock piles or dumps are judged to contain sufficient mineral value to justify leaching and the solutions can be controlled without

[3]Reference to specific products does not imply endorsement by the Bureau of Mines.

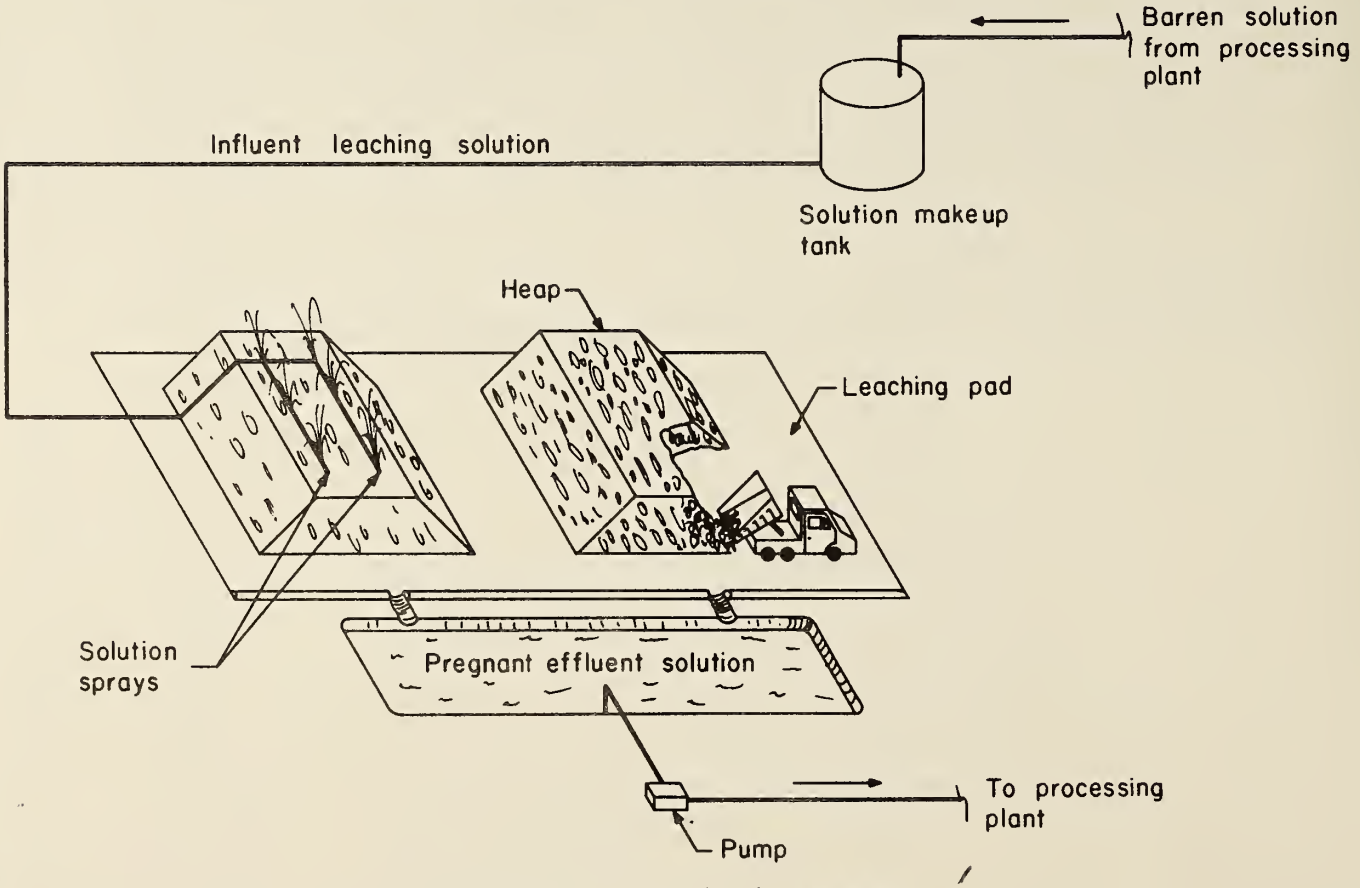

FIGURE 1. - Heap leaching system.

FIGURE 2. - Typical pilot heap leaching operation.

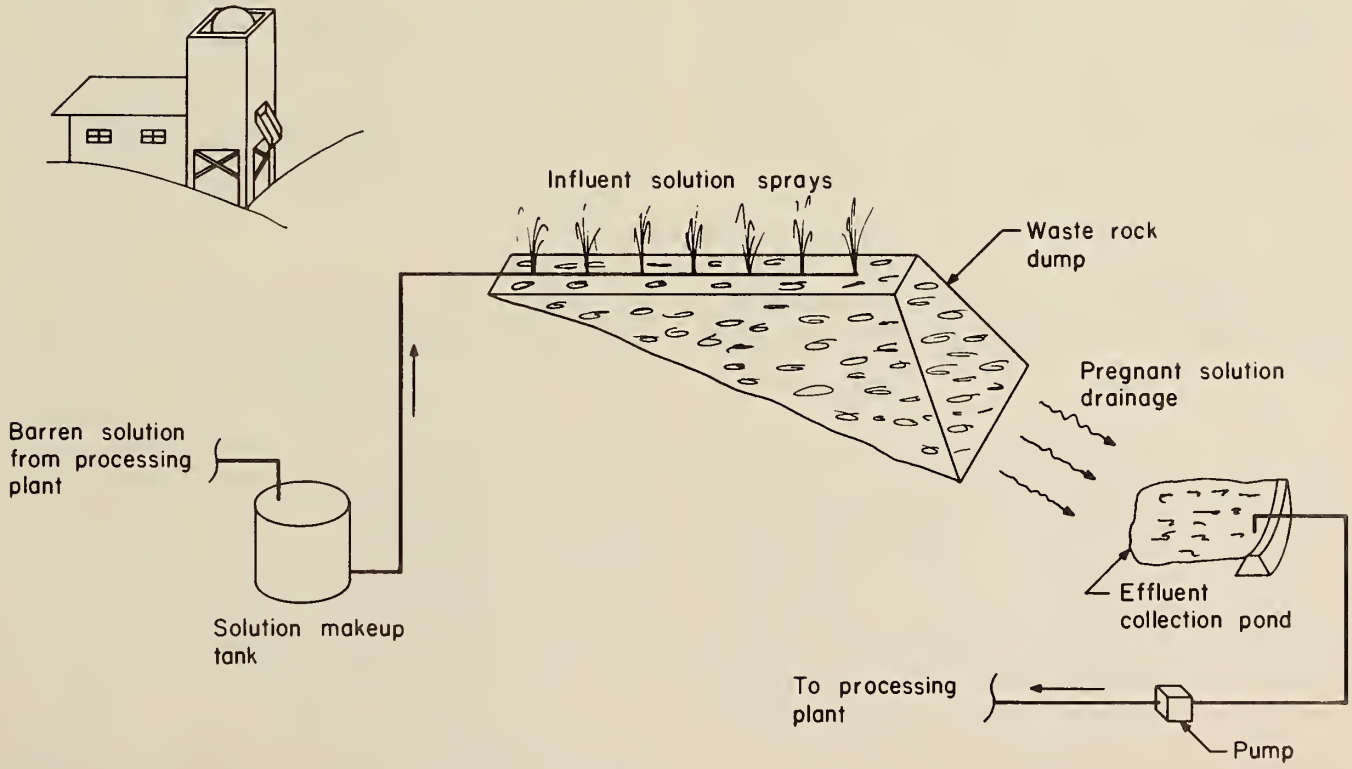

FIGURE 3. - Dump leaching system.

appreciable losses, the pile is "dump" leached without any preparation (fig. 3). Although this technique is rarely used for leaching gold and silver, it is common in the copper industry.

Finally if the ore is broken and left in place or if it conducts fluids flow without blasting, it can be leached "in situ" or in-place (fig. 4). An exposed ore body can be leached in situ by spraying solution on the surface and collecting it in recovery wells after it has percolated down through the ore. For buried ore bodies, the solution must be injected into the formation through injection wells and recovered from adjacent recovery wells. Although copper and uranium have been leached in situ, there have been only sporadic attempts to develop such operations for leaching gold and silver. One attempt to in situ leach gold at the Ajax Mine near Victor, CO, is described later.

Since many operators are considering leaching gold and silver for the first time or are experiencing problems in establishing leaching operations, this report summarizes leaching principles and practices, discusses problems that may be encountered, and lists sources of additional information in a bibliographic appendix.

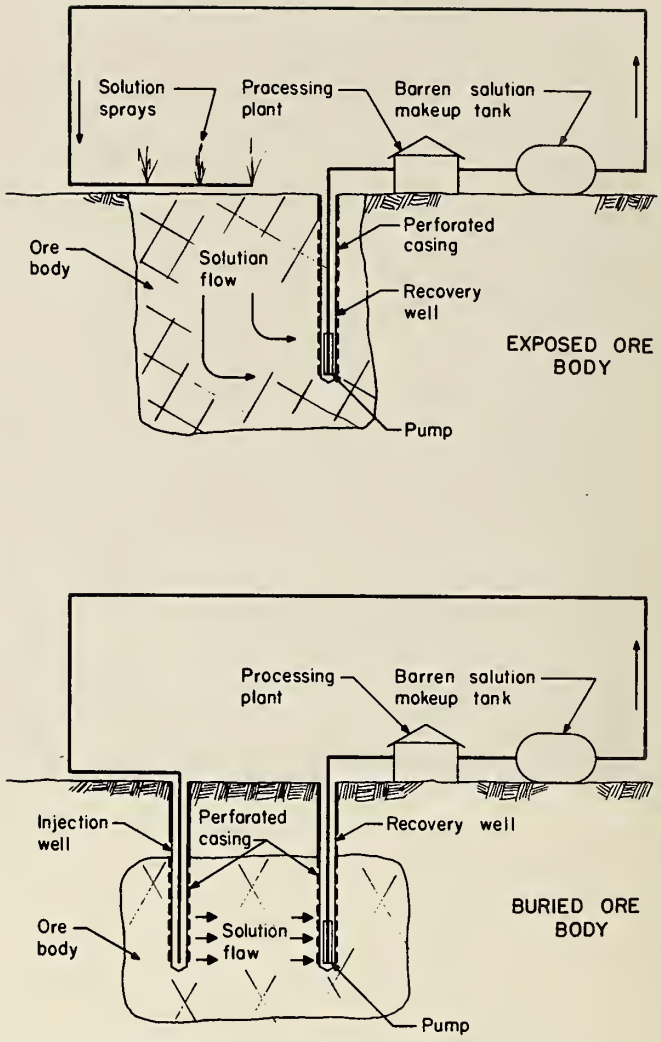

FIGURE 4. - In situ leaching systems.

ACKNOWLEDGMENTS

The authors wish to express appreciation to the following mining companies that provided engineering data on their leaching experiments or operations:

Company	Location
American Selco, Inc.	Reno, NV
Can-American Mining Co.	Tombstone, AZ
Carlin Gold Mining Co.	Carlin, NV
Congress Consolidated Coal Mining Co.	Phoenix, AZ
Cyprus Exploration Co.	Carson City, NV
D Z Exploration Co.	Lovelock, NV
Gold Creek Corp.	Eureka and Ely, NV
Gold Resources Joint Venture	Cripple Creek, CO
Golden Arrow, Inc.	Las Vegas, NV
Hildebrand Drilling	Phoenix, AZ
Landusky Mining Co.	Landusky, MT

Company--Con.	Location--Con.
Occidental Minerals Corp.....	Hawthorne, NV
Placer Amex Inc.....	San Francisco, CA
Scholz Minerals Engineering, Inc.....	Helena, MT
Silver Ridge Mining Co.....	Tombstone, AZ
Smoky Valley Mining Co.....	Round Mountain, NV
State of Maine Mining Co.....	Tombstone, AZ
Tombstone Exploration, Inc.....	Tombstone, AZ
Vekol Mine Development Co.....	Chandler, AZ
Windfall Venture.....	Eureka, NV
Zortman Mining Co.....	Mica, WA

MINERALOGY

Since many good references are available on the geology of gold deposits, such information is not provided herein. Of particular importance however, in evaluating the leachability of gold-silver deposits is their mineralogy.

Gold is usually deposited as native or free gold associated with pyrite (5).[4] Occasionally, as at Cripple Creek, CO, the gold is deposited as a telluride. Various heavy metal compounds are frequently associated with the gold.

Silver is usually deposited in its compound form. Besides native silver (Ag), those minerals containing leachable silver are argentite (silver sulfide, Ag_2S), cerargyrite (silver chloride, AgCl), embolite (AgCl, AgBr), and bromyrite (silver bromide, AgBr). Other silver minerals are not readily leachable (12, 24).

Ore can be economically leached at grades about an order of magnitude lower than they are commonly milled. Current leaching operations are producing gold from ores containing as little as 0.03 oz/ton with cutoff grades down to 0.01 oz/ton. Most silver leaching operations produce from ores grading 1 to 4 oz/ton. The easiest ores to leach are those that have been weathered or oxidized, liberating the gold or silver from pyrite or other encapsulating minerals.

A variety of mineralogical conditions can hamper or prevent leaching of an ore. For example, deposits that contain organic carbon are not suitable because the carbon prevents much of the gold from dissolving and adsorbs any dissolved metal before the leach solutions are recovered. Other refractory ores are those in which the gold or silver is totally encased by an impervious matrix material such as quartz so that the leaching solutions cannot contact the metal. Copper, cobalt, and zinc in the ore may preferentially take the place of gold and silver in the leaching reaction and greatly reduce the reaction with the desired metal.

Some ores, such as tellurides or those containing arsenopyrite or antimony, must be roasted before they can be leached with cyanide and so are not amenable to heap leaching (12). Although other leaching solutions have been investigated for use with telluride deposits, no commercial heap leaching operations have resulted.

Pyrrhotite is another mineral that complicates leaching. Decomposition of pyrrhotite in cyanide produces ferrocyanide, which removes free cyanide from solution and prevents its reaction with the gold or silver. This decomposition also removes oxygen from the solution, which further decreases the reaction with gold and silver.

If manganese occurs with silver ores, its higher order oxidation products can

[4]Underlined numbers in parentheses refer to items in the list of references preceding the appendix.

form refractory compounds of silver and manganese (8, 38). Many silver deposits were left unmined throughout the Western United States because of this particular problem. Some of these deposits may be amenable to dual leaching, first with aqueous SO_2 to recover manganese, followed by neutralization and leaching with cyanide to recover silver.

Clay minerals in the ore pose a major problem in leaching operations. The clay particles block the leaching solution's flow through the ore and isolate large portions of ore from the solution. Some heaps contain so much clay that the solution perches on top with negligible downward percolation.

LEACHING TECHNOLOGY

HEAP LEACHING ORE PREPARATION

Ore preparation for heap leaching consists of (1) preparing an impervious pad, (2) mining or gathering ore from dumps, (3) crushing the ore (optional), and (4) placing the ore on the pads.

Pads are usually situated in flat terrain that is graded to provide gently sloping surface for drainage (2 to 5 pct). Next the pad site must be lined to prevent solution seepage losses. If plastic liners are used, the ground is covered with a layer of sand or tailing that is rolled to provide a cushion. The liner sections are laid out and cemented together, then covered with sand to provide additional cushioning. Heaps that are subjected to much vehicular traffic are often lined with asphalt. Some pads are merely lined with a thick clay or tailing layer that becomes essentially impervious when wet. A dam or berm with a drain is constructed on the downstream end of the pad to direct the solution into a holding pond.

Size distribution of ore placed on heaps ranges from run-of-mine to minus 1/4 in (6 mm). Many miners crush the ore to significantly improve total recovery and recovery rates. Operating costs are, of course, higher when ore is crushed. Before an operator selects a particular particle size, the ore should be tested to determine the trade-off between mineral recovery and crushing costs at several sizes.

Ore is spread on the prepared pads by scrapers, front-end loaders, trucks, and bulldozers; conveyors and stackers can also be used. A unique gantry system has been employed at one operation in New Mexico (22). Since solution percolation into a heap is severely affected by any packing from driving on the surface of the heap, the specific technique by which the ore is placed in heaps profoundly influences precious metal recovery. Techniques that eliminate traffic on the implaced ore are strongly urged.

Each layer, called a lift, is usually placed 5 to 10 ft (2 to 3 m) deep; the range encountered at current operations was 2 ft (1 m) to 20 ft (7 m). Although it has long been felt that after solutions percolate through a heap greater than about 10 ft (3 m) deep, they may become oxygen deficient, the rate of oxygen depletion has not been accurately measured. Recent experiments with hydrogen peroxide additives have shown no increased metal recovery (40), which would indicate that the critical oxygen content is not as high as originally envisioned.

After the first lift has been leached, either it is removed from the pad, or the next lift is placed on top of it so that subsequent applications of leaching solutions will percolate through both. A third and fourth lift can be added later. Operations using fine ore size generally leach with only one lift because at the end of the leaching cycle the ore is virtually depleted and may as well be removed. Operations with larger sized ore particles that take longer to leach generally use multiple lifts. The solution can then pick up extra mineral values from the lower lifts until they are depleted without wasting valuable pad space.

Placing ore on heaps so as to prevent surface packing is a problem. If vehicular traffic packs the surface into a hard

pan, the leaching solution will not percolate uniformly downward; in fact, stagnant puddles or ponding on the surface may occur. Although packed material can be loosened with a ripper, several companies are considering conveyor systems to eliminate vehicular traffic on heaps. Pushing the material into place with a front end loader after it is dumped on the pad also minimizes surface packing.

Where clay in the ore causes percolation problems, a relatively new technique of agglomerating the fines can be used to prepare the ore. Devised by the Bureau of Mines' Reno Research Center, the technique dramatically improved percolation rates, prevented channeling, and improved leaching rates in pilot tests (26-28). Several companies have used the technique in full-scale operations since 1980. At one of these sites, recovery improved from 37 to 90 pct as a result of agglomeration. The technique involves mixing the dry crushed ore with 5 to 15 lb/ton (2.5 to 7.5 g/kg) portland cement, wetting with 8 to 16 wt pct water, mechanically tumbling the wetted feed to effect agglomeration, and curing the agglomerated material for 72 h prior to leaching. The lime in the portland cement reduces the amount of lime that must be added to the leaching solution to maintain the proper pH; see the following section on leaching solutions. Even greater benefits accrue if, instead of using water, the cement-ore mixture is wetted with relatively strong cyanide solution during agglomeration. This cyanide solution can then begin precious metal dissolution while the pellets are curing so that the heap can be leached with water that can be recirculated throughout the leaching cycle. Preliminary tests resulted in reduced cyanide consumptions and reduced leaching time.

DUMP LEACHING ORE PREPARATION

Although waste rock from either underground or open pit mines is of too low a grade to warrant conventional milling, some gold or silver may be recovered by leaching it. If dumps are leached without additional ore preparation or transporting the rock to prepared pads, the operation is termed a dump leach. Caution must be exercised in selecting dumps to insure that no leach solutions can escape into ground water or surface water drainage. A heavy clay soil underlying the dump is necessary to prevent solutions from percolating to the ground water. Dams are generally constructed to trap and hold the leach solutions.

IN SITU LEACHING ORE PREPARATION

There are no commercial-scale in situ gold or silver leaching operations in the United States. If such leaching is undertaken, ore will probably be prepared by blasting the formation to rubblize it. For shallow deposits [less than 300 ft (100 m)] the deposits would be rubblized with explosives placed in vertical holes patterned after techniques used for in-place copper leaching (9-10). Deep deposits would require blasting methods similar to those employed at conventional underground mines. For instance, if a deposit would be developed by a certain stoping configuration for conventional mining, the same configuration would likely be the most efficient for preparing the ore for in situ leaching. The only difference would be that in conventional operations all of the rock from development openings and ore from the stopes is hauled to the surface, whereas in leaching operations only the 20 to 25 pct of this material would be hauled to the surface to provide "swell" space for the rubblization blast.

Certain shallow underground mines in well-fractured formations may be amenable to in situ leaching without any ore preparation. Access to the deposit would be gained via the mine development openings; solution injection and recovery wells could be drilled from any of these openings at possible cost savings (by eliminating drilling through barren overburden). Placer gold deposits would probably be permeable enough to permit leaching from vertical wells without blasting (33).

LEACHING PROCESS

Leach Solutions

Although it is possible to leach gold and silver with several types of solutions, all current operations use sodium cyanide (NaCN), mixed in water at strengths of about 1 lb/ton (0.5 g/kg) of solution, or 0.05 pct. Strengths encountered in current operations range from 0.3 to 5.0 lb/ton (0.15 to 2.5 g/kg). The higher strengths are generally used on ores with high silver content.

When the cyanide solution contacts free gold or silver, leaching occurs according to the following reactions (2, 12):

$$2Au + 4NaCN + O_2 + 2H_2O \rightarrow 2NaAu(CN)_2 + H_2O_2 + 2NaOH$$

and

$$4Au + 8NaCN + O_2 + 2H_2O \rightarrow 4NaAu(CN)_2 + 4NaOH.$$

The reaction depends strongly on oxygen, which is added by bubbling air through the solution and/or by spraying the solution onto the heaps.

When other silver minerals are leached, the silver similarly combines with the cyanide ion except that silver chloride apparently will combine without oxygen (24); for instance,

$$AgCl + 2NaCN \rightarrow NaAg(CN)_2 + NaCl.$$

Leach solutions are effective at pH 9.5 to 11, although both lower and higher alkalinities have been successfully used. Lower pH may result in decomposition of the cyanide by hydrolysis or by reaction with carbon dioxide in the air. Low pH can also permit gasification (and hence loss) of the cyanide if the solution contacts natural ground acids (19). Conversely, excessively high alkalinity seems to retard the reaction. The desired pH is maintained by adding lime (CaO) or caustic soda [sodium hydroxide (NaOH)] at about 0.5 to 1.0 lb/ton (0.25 to 0.5 g/kg) of solution. Although caustic soda is more expensive, it reduces maintenance problems caused by lime scale. Some operators claim that both the cyanide concentration and pH should be higher for silver ores than for gold ores, but no trend could be discerned from the engineering data available.

Solution Distribution

Leach solutions are pumped from a mixing pond to the distribution site after the cyanide and lime (or caustic soda) have been added. Upon reaching the site, the solution travels through a grid of distribution lines (usually 3/4- to 2-in-diam plastic tubing) deployed across the top of the heap or dump. Spray nozzles, sprinkler heads, or wriggler tubing connected at various intervals into the main distribution line apply the solution.

Fixed-spray systems are the cheapest and easiest to install; some operators merely punch holes in the distribution lines at fixed intervals to create a spray (fig. 5). Although these require little maintenance, channeling is a common problem. Other operators may attach short feeder lines connected to fixed lawn-type sprinklers, but these do not distribute the solution as uniformly as do other systems and frequently result in channeling.

The most common solution distribution system is the oscillating lawn sprinkler, usually referred to as the rainbird sprinkler (fig. 6). This sprinkler gives a more uniform coverage than fixed sprays. These sprinklers are, however, susceptible to calcium salt scale, which restricts the flow. When the scale severely restricts solution flow, the sprinklers must be removed and soaked in hydrochloric acid to dissolve the calcium salts. Some operators have experimented with modifying the sprinkler orifice in an attempt to reduce this problem and to distribute the solution without the ring of more concentrated sprinkling that seems common from off-the-shelf sprinklers. Sprinklers are generally operated

FIGURE 5. - Fixed-spray solution distribution.

FIGURE 6. - Rainbird sprinkler.

with 20 to 40 lb/in^2 (0.14 to 0.28 × 10^6 Pa) line pressure, which yields a radius of coverage averaging 35 to 50 ft (11 to 15 m).

The so-called Bagdad wiggler, named for its development at Cyprus' Bagdad Mine in Arizona, has recently become popular. A wiggler is constructed by cutting a 9-in (23-cm) long segment of 1/4-in (6-mm) thick-walled gum rubber tubing and forcing one end over a hose connection attached to the feeder lines (fig. 7). As the solution passes through the tubing, the free end wiggles and sprays the solution around in a circle. Wigglers are generally placed on 10-ft (3-m) centers. If the wiggler flops in a figure 8 instead of a circular path, the ends are sliced with three short spiral cuts. Proponents argue that wigglers have better distribution patterns than sprinklers. Maintenance is relatively easy; when calcium salt scale appears in the lines, the wiggler can be stretched and shaped to dislodge the buildup. Wigglers are operated at around 20- to 40-lb/in^2 (0.14 to 0.28 × 10^6 Pa) line pressure.

An even newer but similar solution distribution technique employs the use of a wobbler. Wobblers are made by attaching lengths of thin plastic (Tygon) tubing to the solution feeder lines. At normal operating pressures the wobblers will produce a 4-ft (1.2-m) high spray with a radius of 9 ft (3 m).

At least two operators are applying solutions by ponding (fig. 8). Leach solutions are directed over the top of the heaps, where berms and dams hold the solution in a pond. The pond is kept several inches deep as the solution percolates downward. A major disadvantage is that appreciable clay-size particles in the heap or dump material will thwart percolation and will promote channeling drastically. Another problem with ponding is maintaining sufficient oxygen in the solution for efficient dissolution of gold and/or silver.

Regardless of the distribution method, after percolating through the ore the solution drains off the pad into a holding pond (fig. 9). The pond is lined with

FIGURE 7. - Bagdad wiggler.

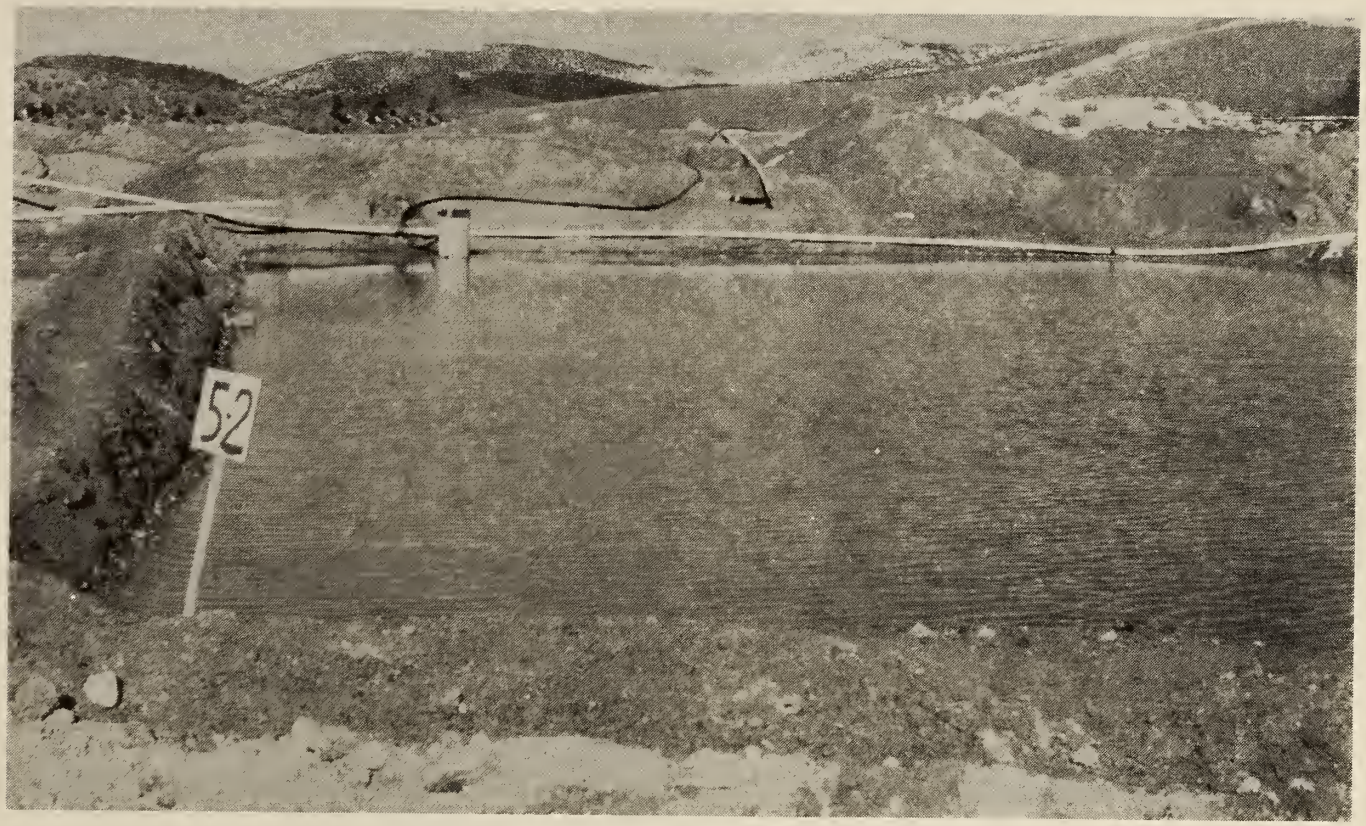

FIGURE 8. - Solution distribution by ponding.

FIGURE 9. - Pregnant effluent solution collecting pond.

plastic sheet or a clay layer to prevent seepage. The pond functions both as a surge pond and as a settling basin for particles contained in the pregnant solution. Settling rates may be increased by adding a flocculant.

Solution application rates vary among operators. Generally the rate should be kept below that which would cause the solution to pond on the surface and then channel through the ore heap or dump. Experiments at several sites have indicated optimum leaching rates of around 0.005 gal/min·ft^{-2} (3×10^{-4} mL/s·cm^{-2}) of pad area; rates at commercial operations range from that figure up to 10 or 20 times higher. Recovery plants have been established to handle throughput rates of 50 to 3,000 gal/min (3 to 18 L/s).

RECOVERY

Comparison of Techniques

Gold and silver are recovered from the pregnant solutions by precipitation with zinc dust or by adsorption on activated carbon in the form of charcoal. Each method had advantages and disadvantages. Selection of a specific system will depend on the specific conditions at a leaching operation and the facilities already available.

Most of the conventional mill circuits were based on the Merrill-Crowe system for precipitation of gold and silver by zinc dust. Although the capital expenditure required to establish such a system has been high, there are now on the market, small packaged plants designed and priced for small leaching operations. Costs are reduced in these systems by eliminating the high-cost, countercurrent decantation circuit used in a conventional milling circuit.

Where an old mill circuit can be converted to handle a leaching system, zinc precipitation usually costs less than charcoal adsorption. The low cost of zinc also favors zinc precipitation systems. One hundred pounds of zinc dust costs about $35 and will precipitate 600 to 800 oz of gold, while the amount of activated carbon needed to adsorb about the same amount of gold (about 1 ton) costs $2,500. Although the zinc is expended, 70 cycles must be achieved with the charcoal to balance the material costs. Zinc precipitation also does not require the capital and operating costs of a charcoal-stripping plant and kiln for reactivating the charcoal.

If more silver than gold occurs in the leach solution, zinc precipitation offers a further advantage because with charcoal adsorption, a large volume of high-cost material is tied up adsorbing a lower value metal. The problem of recovering silver in leach solutions has been somewhat alleviated by recent Bureau research (21), which has demonstrated that silver can be effectively precipitated from the leaching circuit as Ag_2S by adding sodium sulfide; the solution can then be passed through the carbon adsorption columns to recover the gold.

Carbon adsorption systems are, however, becoming increasingly popular, and they do have several advantages over zinc precipitation systems. The primary advantages of carbon adsorption are that the systems can adsorb metals from solutions that contain suspended solids and from solutions that contain low metal concentrations (less than 0.05 oz/ton of solution) (20-21). Charcoal adsorption also does not require a filtration system nor a de-aeration tank and pump. Environmental damage from zinc salts is avoided.

Zinc Precipitation

A generalized flow diagram for precipitating gold and/or silver with the zinc system is shown in figure 10. First, pregnant solutions are pumped from the holding pond to the processing plant. Since suspended particles will coat the zinc and retard its reaction, the first step of the process is to filter the solution (usually with plate and frame filters). The filters are often coated

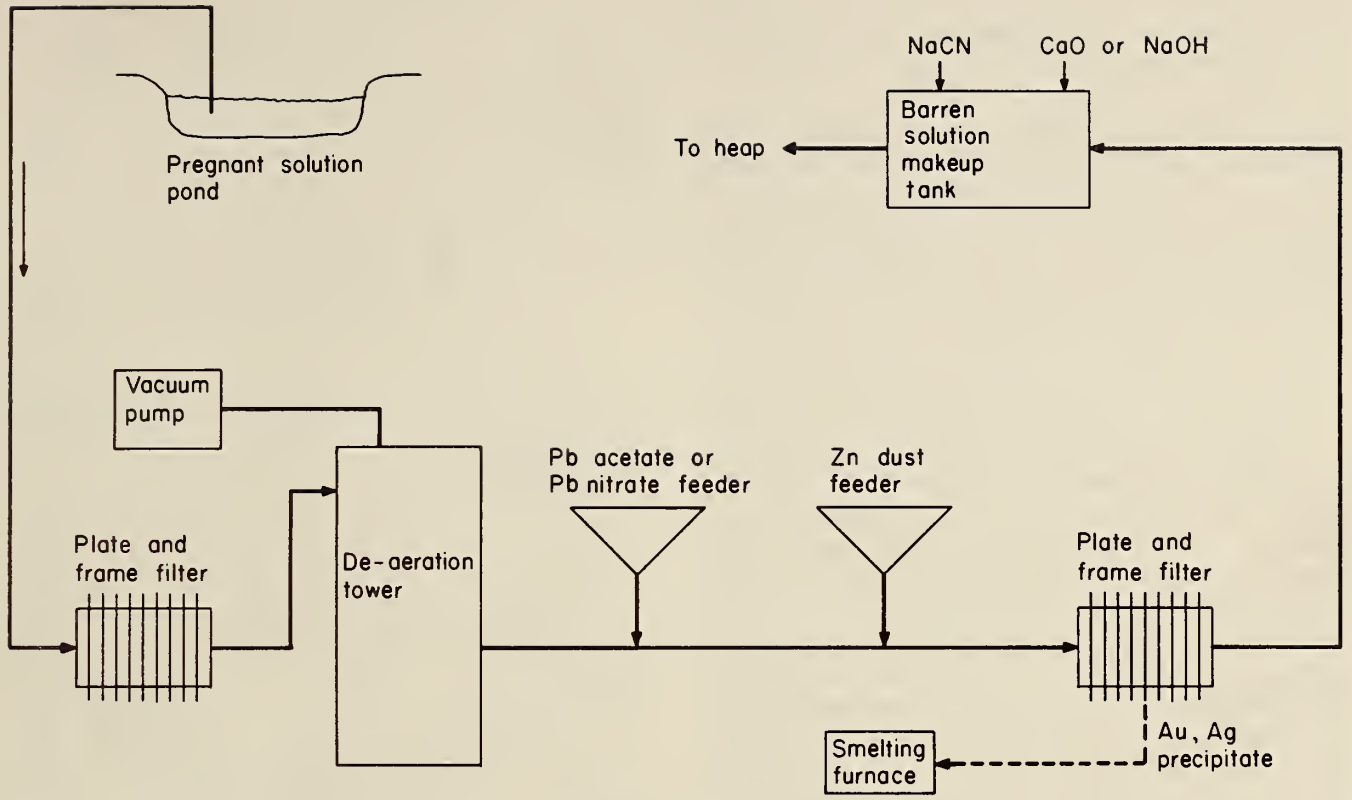

FIGURE 10. - Zinc precipitation recovery system.

with diatomaceous earth to help remove the suspended particles and prolong filter life.

Gold and/or silver precipitation also depends on complete removal of dissolved oxygen. Although this is usually achieved by a Crowe-type vacuum tank and pump, air can also be removed by sand filters and ceramic baffles. Failure to remove the oxygen permits the precipitated gold and silver to be redissolved. Even more importantly, any oxygen present when zinc dust is added forms hydrated zinc oxide, which coats the zinc and prevents further reaction with the solution.

Gold and silver precipitation are improved by adding lead acetate or lead nitrate to the solution. The lead forms a bond with the zinc that has a greater galvanic activity than the zinc alone and precipitates the precious metals faster. The lead acetate or nitrate added is about 10 wt pct of the zinc dust. Care must be taken to prevent coating the zinc with too much lead, which retards the galvanic action. Silver in the solution can form the same galvanic couple as does lead with zinc, so that adding lead acetate is often unnecessary for leaching solutions containing appreciable silver.

Zinc dust is fed into the solution by a screw-type feeder and cone arrangement. Precipitation proceeds according to the following reaction (12) for gold and silver:

$$NaAu(CN)_2 + 2NaCN + Zn + H_2O$$

$$\longrightarrow Na_2Zn(CN)_4 + Au + H + NaOH.$$

Since the zinc should precipitate gold or silver 1 mol/mol, approximately, equivalent amounts of zinc should be added as there are precious metals in the solution. In actual practice, anywhere from 10 to 100 pct more zinc is added than theoretically should be needed. Enough free cyanide must be present to dissolve the zinc so that it can replace the gold in the alkaline compound and so that the resulting zinc alkaline compound remains

in solution. The accompanying liberation of hydrogen is necessary to create the reducing conditions for precipitation.

After the zinc has been added to and mixed with the leach solution, the solution is forced through Merrill-type pressure filters. This leaves behind the gold and/or silver plus impurities. The precipitate is removed from the filter and dried for smelting.

For either all-gold or all-silver precipitates, a flux is added and the precipitate is smelted for pouring. If both gold and silver are present in significant amounts, the precipitate can be fluxed and smelted for sale as a doré bullion. If separating the gold and silver is desired, silver can be dissolved from the filtered precipitate with nitric acid and electrowon from the solution. The remaining precipitate is smelted for obtaining its gold. As an alternative, gold can be separated from the precipitate by dissolving it in aqua regia and then recovered by precipitating it from the aqua regia with oxalic acid or by electrowinning it.

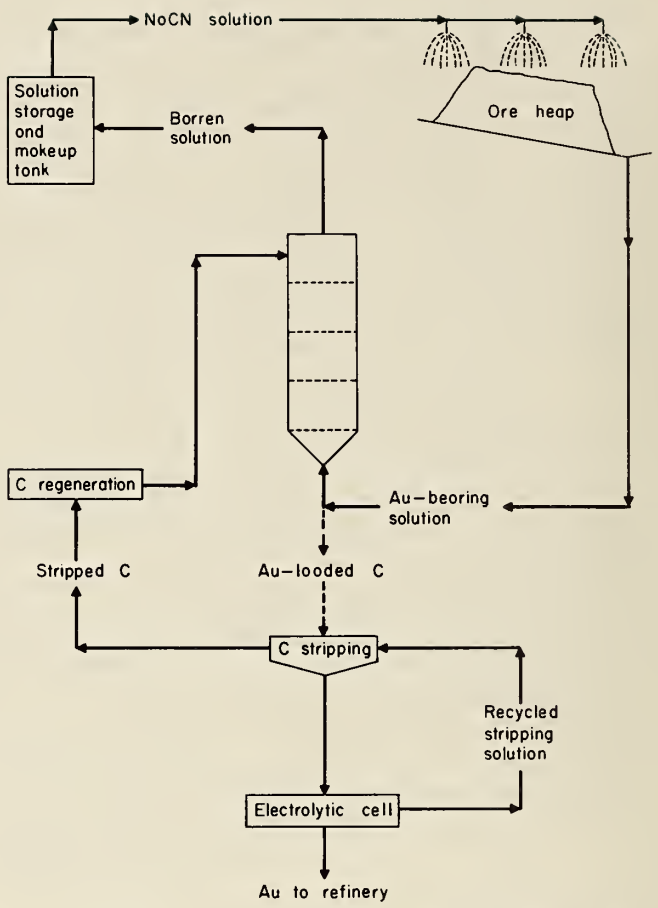

FIGURE 11. - Charcoal adsorption recovery system (after Potter (36)).

Charcoal Adsorption

Charcoal adsorption systems for recovering gold and silver (fig. 11) have been described in great detail (21). First, the pregnant leaching solution is pumped from the holding pond to the processing plant, where it flows through three to five carbon columns. Each column contains granular activated carbon manufactured from coconut shells (minus 6 plus 16 mesh or minus 12 plus 30 mesh). The pregnant solution can be percolated down through a fixed bed of the charcoal in each column, or it can be directed upward through the charcoal at a rate that maintains the charcoal in a suspended state (fluidized). Although columns with fixed beds require less charcoal for the same amount of solution, they are more susceptible to plugging from particles carried in the solution than are those with fluidized beds. Most commercial operations, therefore, use fluidized beds. Flow rates required to maintain a fluidized condition range from 15 to 25 gal/min·ft^{-2} (1 to 1.7 L/s·cm^{-2}), depending on the size of activated carbon used.

The columns of charcoal are arranged in countercurrent series so that the fresh solution first enters the column that contains the charcoal with the most adsorbed precious metals. As the solution flows through the charcoal, gold and silver are adsorbed onto its surface. The solution passes through columns containing charcoal with successively less adsorbed metals until it emerges as a barren solution from the last one. After emerging from the last column, the barren solution is pumped to the makeup pond.

When the front column of carbon (or a portion of it) reaches its desired loading capacity, the carbon is removed for stripping. An identical amount of carbon is then removed forward in each column,

and a fresh charge is added to the last. Charcoal loading formerly ranged from 400 to 800 oz of metal per ton of charcoal (14 to 27 g/kg); a recent trend towards lower loading and more frequent stripping commonly results in loading levels of 150 to 250 oz/ton carbon (5 to 9 g/kg). Factors that affect charcoal loading are solution grade, flow rate, gold-to-silver ratio, solution pH, charcoal type, and impurity concentrations.

The loaded charcoal removed from the columns must be stripped of the precious metals. Stripping is accomplished with a hot caustic soda solution. The traditional Zadra process involves soaking the loaded charcoal at 93° C in a 1.0 pct NaOH-0.1 pct NaCN solution for 24 to 48 h (42-43). By adding 20 pct ethanol or methanol to the solution, the time can be reduced to 5 or 6 h (20). The stripping time and chemical consumption can be further reduced by pressure stripping (37) with a 0.4-pct NaOH solution (without NaCN) at 150° to 200° C and 50 to 90 lb/ in (0.3 to 0.6 10 Pa).

Gold or silver are next removed from the stripping solution by electrowinning. Typical electrowinning cells contain a stainless steel anode plus a stainless steel wool cathode for plating the metal. The steel wool cathode is usually packed to a density of 1 lb/ft (16 kg/m) and provides a cathode surface area of 10 ft /lb (2 m /kg). Operating voltages run from 2.5 to 3.5 V. Significantly higher voltages can break down the solution and generate hydrogen or ammonia gas, which blocks the plating action. Current ranges from 20 to 30 A, which provides a current density of 3 to 3.5 A/ft at the cathode. The solution should be retained in the cell at least 15 min, preferably 30, to win the gold and silver.

The stripped carbon is regenerated by heating in a kiln or chamber at approximately 700° C (1,300° F) in a reducing atmosphere such as steam. Although carbon can be used two or three times without regeneration, it is simpler to regenerate it each time rather than trying to keep track of which batch needs regenerating. The life expectancy of carbon has not been well documented. Some operators have experienced a 25-pct reduction in adsorptive capacity after eight or nine cycles, while others have found only a 33-pct reduction after 8 or 9 yr of continuous use. A few operators simply sell the gold- and/or silver-laden charcoal for smelting rather than stripping it. That charcoal is, of course, destroyed during the process.

LEACHING OPERATIONS

Over 80 operations have been identified that have experimented with leaching, were actively leaching, or were seriously planning on leaching (fig. 12). Although many of these reported activities could not be verified, table 1 presents available information on their status along with a general location, mine name, and operating company. The many new permits being granted each year indicate the great interest in leaching but make it impossible to generate a totally up-to-date list of operations.

The 26 operations for which the most data were available were selected for presentation of geologic and operational parameters. Table 2 provides the location information for each, table 3 the ore characteristics and leaching data, and table 4 the extraction data. While the data contained in these tables will change, it is felt that operators or potential operators can use them to develop a feel for the range of conditions that can be expected at a particular site. The tables can also indicate possible solutions to site-specific problems. A State-by-State summary of leaching operations follows.

TABLE 1. - Gold and silver heap and dump leaching operations in the Western United States

State and county	Company	Mine	Mineral	Status
Arizona:				
Cochise	Tombstone Exploration, Inc.	Contentation	Silver	Active.
Do	State of Maine Mining Co.	State of Maine	Cerargyrite	Do.
Do	Minerals 71 (Sierra Minerals).	NA	Silver	Inactive.
Do	Silver Ridge Mining-Houston Mining and Resources.	Nicholas, Gambasino, Rattling Boy, Stuck Steel.	Gold, silver	Planned.
Do	Can-American Mining Co.	Dry Hills	Silver	Active.
Pinal	Vekol Mine Development-Sunburst Mining Co.	Vekol	Cerargyrite, bromyrite.	Do.
Yavapai	New Jersey Zinc	Silver Clip, Black Rock	Silver	Planned.
Do	Congress Consolidated Gold	Congress	Gold	Active.
Do	Walter Statler	Little Jessie	...do	Inactive.
Yuma	Dr. Eugene Burdick	North Star	...do	Planned.
Do	Magini Leasing and Contracting	Robinson Claims	...do	Do.
Do	Hildebrand Drilling	San Marcos	...do	Active.
Do	Red Cloud Mining	Red Cloud	Cerargyrite	Planned.
NA	AMCA Industries, Ltd.	Silver Cross	Silver, gold	Active.
California:				
Imperial	Chemgold, subsidiary of Glemis Gold, Ltd.	Picacho	Gold	Do.
Colorado:				
Costilla	E & B Mining	NA	...do	Unknown.
Gilpin	Nuclear and Minerals Corp.	Leaching site	...do	Do.
Do	Saratoga Mines, Inc.	Saratoga	...do	Active.
Mineral	Minerals Engineering-Chevron Resources Co.	Emperius	...do	Do.
Do	Minerals Engineering	Cowboy Johnson (Corsair)	Silver, gold	Inactive.
Rio Grande	Draco Mines, subsidiary of Southern Cross, Ltd.	NA	Gold	Planned.
Teller	Gold Hills Mesa Corp.	NA	NA	Unknown.
Do	Gold Resources Inc.-Newport Minerals Inc.	Globe Hill	Gold	Active.
Do	Gold Ore, Ltd.	NA	...do	Do.
Do	Golden Cycle Corp.-Texasgulf Inc.	Ajax	Calaverite	Conventional.
Do	Merchant-Caithness Joint Venture--Venture Mining.	Stratton Estates	NA	Unknown.
Do	National Energy Corp.	Midget, Moon Anchor, Red Bird, Yellow Bird, Dolly V, Atlas, Loan Jack.	Silver, gold	Do.
Do	Gold Ray Mining	Gold Ray	Gold	Do.
Do	Yellow Gold of Cripple Creek, Inc.	Rittenhouse	...do	Planned.

Idaho:				
Custer.....	NA.....	NA.....	...do.....	Do.
Valley.....	Canadian Superior Mining-Ranchers Exploration and Development.	Yellow Pine, West End, Garnet Creek..	Gold, antimony	Do.
Do.....	Phillips Petroleum-Thunder Mountain Gold, Inc.	Sunnyside Mine and surrounding claims	Gold.....	Do.
Montana:				
Broadwater....	United Minerals.....	NA.....	...do.....	Do.
Jefferson.....	Lacana-Falcon Exploration.....	Tourmaline Queen.....	NA.....	Active.
Do.....	Placer Amex.....	Golden Sunlight.....	Gold.....	Planned.
Phillips.....	Pickle Crow Exploration.....	NA.....	Silver, gold..	Unknown.
Do.....	Zortman Mining Co.-Pegasus Explorations, Ltd.	Ruby Gulch.....	Gold, silver..	Active.
Do.....	Landusky Mining Co.-Pegasus Explorations, Ltd.	August, Gold Bug.....	...do.....	Do.
Powell.....	Adams Bros. Construction.....	Viking.....	Gold.....	Planned.
Nevada:				
Churchill.....	Desert Star Mining.....	Desert Star.....	Gold, silver..	Active.
Do.....	Fisk and Son.....	Gold Hill.....	Gold.....	Do.
Clark.....	Crescent Mining, Ltd.....	Rest.....	...do.....	Do.
Do.....	Big Delta Refinery, Inc.....	Dawn Renae.....	...do.....	Do.
Do.....	Intermountain Exploration Co..	NA.....	Gold, silver..	Unknown.
Elko.....	Tuscarora Associates.....	Tuscarora Mine.....	...do.....	Active.
Do.....	McNeely Mining Contractors, Inc.	NA.....	...do.....	Unknown.
Esmeralda.....	Diablo Mine Services Co.....	NA.....	Gold.....	Do.
Do.....	Mid-Continent Mining-Sunshine Mines.	Nivloc Sixteen to One Properties.....	NA.....	Inactive.
Do.....	Falcon Exploration.....	Tonopah-Divide.....	Gold.....	Planned.
Eureka.....	Windfall Venture.....	Windfall.....	...do.....	Active.
Do.....	Carlin Gold Mining Co.-Newmont Mining.	Carlin, Bootstrap.....	Gold, mercury.	Do.
Do.....	...do.....	Maggie Creek.....	Gold.....	Do.
Do.....	...do.....	Gold Quarry Prospect.....	...do.....	Planned.
Do.....	Cominco American, Inc.....	Buckhorn.....	Gold, silver..	Active.
Humboldt.....	Bauer Metals, Inc.....	Martin Creek.....	Silver.....	Do.
Do.....	Lion Mines, Ltd.....	NA.....	Gold, silver..	Planned.
Do.....	Pinson Mining Co.....	Pinson, Preble.....	Gold.....	Active.
Lander.....	Placer Amex-Bunker Hill Cortez Gold.	Cortez, Gold Acres, Horse Canyon.....	...do.....	Do.
Do.....	Minex Resources, Inc.-Klondex Mines, Ltd.	Firecreek.....	...do.....	Do.
Do.....	New Pass Resources, Inc.....	New Pass Mill.....	Gold, silver..	Do.
Do.....	Aaron Mining, Inc.....	Gold Quartz.....	...do.....	Do.

TABLE 1. - Gold and silver heap and dump leaching operations in the Western United States--Continued

State and county	Company	Mine	Mineral	Status
Lander.....	Duval Corp.....	Copper Canyon, Battle Mountain.....	Gold, silver..	Active.
Mineral.....	Nerco Metals Co.....	Candelaria Project.....	...do.....	Do.
Do.....	Houston International Minerals	Borealis.....	...do.....	Do.
Do.....	Hugh C. Ingle, Jr.....	Ashby Mine and mill.....	Gold.....	Do.
Do.....	Ladd Enterprises.....	Ladd Tungsten Claims.....	Silver, gold..	Unknown.
Nye.....	Smoky Valley Mining Co.-Copper Range Co.	Smoky Valley.....	Gold.....	Active.
Nye.....	Ibex Mining Corp.....	Keystone.....	...do.....	Inactive.
Nye.....	Golden Arrow, Inc.....	Golden Arrow.....	Gold, silver..	Active.
Nye.....	Cyprus Exploration.....	Northumberland.....	...do.....	Do.
Nye.....	Summa Corp.....	NA.....	...do.....	Inactive.
Nye.....	Great American Gold Co.....	Gold Crown.....	...do.....	Active.
Nye.....	Gila Mines Corp.....	Gila Canyon.....	Silver.....	Do.
Pershing.....	Buckeye Mining Enterprises....	Standard Gold.....	...do.....	Do.
Do.....	Ore-Nugget, Ltd.....	Florida Canyon gold deposit.....	...do.....	Do.
Do.....	Flying J Mines.....	Florida Canyon gold mine and mill....	...do.....	Do.
Do.....	D Z Exploration Co.....	Nevada Packard.....	...do.....	Do.
Do.....	Inland Resources.....	Twin Buttes.....	Gold.....	Do.
Do.....	Lacana Mining, Inc.....	Relief Canyon.....	...do.....	Do.
Storey.....	Intermountain Exploration Co..	Comstock Lode.....	Gold, silver..	Unknown.
Do.....	Flowery Gold.....	Flowery, Lady Bryan.....	Gold.....	Do.
Do.....	Minerals Engineering Co.....	Con-Imperial, Con-Chollar, Dayton....	NA.....	Do.
White Pine....	Gold Creek Corp.-Diamond Silverado Exploration.	Diamond Silverado.....	Silver.....	Active.
Do.....	Gold Creek Corp.....	Treasure Hill.....	Lead, silver..	Do.
Do.....	American Selco-Nerco Metals Co.	Alligator Ridge.....	Gold.....	Do.
NA.....	American Pyramid Resources....	NA.....	...do.....	Unknown.
NA.....	Dallas Exploration.....	NA.....	Silver, gold..	Do.
NA.....	El Plata Mine.....	Leopard, Cornucopia.....	Gold, silver..	Do.
NA.....	Volcanic Gold, Inc.....	NA.....	Gold.....	Planned.
NA.....	Aminex Gold.....	NA.....	...do.....	Unknown.
New Mexico:				
Catron.....	Challenge Mining Co.....	Eberle, Confidence.....	Gold, silver..	Planned.
Santa Fe.....	Gold Fields Mining Co.....	Ortiz Project.....	Gold.....	Do.
NA.....	Canorex Development.....	NA.....	...do.....	Inactive.
South Dakota:				
Lawrence.....	Cyprus Exploration.....	Gilt Edge.....	...do.....	Planned.
Do.....	Tiaga Gold Corp.-Wharf Resources.	Anne Creek.....	...do.....	Do.

NA Not available.

TABLE 2. - Location data for key operations

No.	Company name	State	County	District	Location	Mine	Type of operation	Size of operation	Workers
1	Can-American Mining Co.....	Arizona...	Cochise...	Tombstone.....	Sec 15, T 20 S, R 22 E.....	Dry Hills.....	Underground, heap.	1,000 ton/wk....	NA
2	Tombstone Exploration, Inc.	...do.....	...do.....	...do.....	Secs 11 and 12, T 20 S, R 22 E	Contention.....	Open pit and waste rock, heap.	2,000 ton/d.....	40
3	State of Maine Mining Co...	...do.....	...do.....	...do.....	Sec 16, T 20 S, R 22 E.....	State of Maine.	Waste rock, heap..	300 ton/d.....	12
4	Congress Consolidated Gold.	...do.....	Yavapai...	Martinez.....	Sec 23, T 10 N, R 6 W.....	Congress.....	...do.....	6,000 ton/month.	8
5	Hildebrand Drilling.....	...do.....	Yuma.....	Na.....	Secs 11 and 14, T 5 N, R 12 W.	San Marcos.....	...do.....	NA.....	NA
6	Vekol Mine Development-Sunburst Mining Co.	...do.....	Pinal.....	Stanfield.....	Sec 34, T 9 S, R 2 E.....	Vekol.....	...do.....	NA.....	5
7	Gold Resources Inc.-Newport Minerals, Inc.	Colorado..	Teller....	Cripple Creek.	Sec 18, T 15 S, R 69 W.....	Globe Hill.....	Open pit, heap....	10,000 ton/d....	9
8	Phillips Petroleum-Thunder Mountain Gold, Inc.	Idaho.....	Valley....	Thunder Mountain.	NA.....	Sunnyside Mine, other claims.	...do.....	NA.....	NA
9	Canadian Superior Mining-Ranchers Exploration and Development.	...do.....	...do.....	Yellow Pine (Stibnite).	Secs 2 and 11, T 18 N, R 9 E..	West End, Garnet Creek.	...do.....	400,000 ton/yr..	60
10	Placer Amex[1].....	Montana...	Jefferson.	Whitehall (Cardwell).	Secs 19, 29, and 20, T 2 N, R 3 W.	Golden Sunlight.	...do.....	NA.....	4
11	Zortman Mining Co.-Pegasus Explorations, Ltd.	...do.....	Phillips..	Little Rocky Mountains.	Secs 7 and 17, T 25 N, R 25 E.	Ruby Gulch.....	...do.....	1,000,000 ton/yr	20
12	Landusky Mining Co.-Pegasus Explorations, Ltd.	...do.....	...do.....	...do.....	Secs 15 and 22, T 25 N, R 24 E	August, Gold Bug.	...do.....	1,500,000 ton/yr	20
13	Windfall Venture.....	Nevada....	Eureka....	Eureka.....	Sec 2, T 18 N, R 53 E.....	Windfall.....	...do.....	1,500 ton/d.....	42
14	Carlin Gold Mining Co.[2]-Newmont Mining.	...do.....	...do.....	Lynn.....	Sec 15, T 35 N, R 50 E.....	Carlin.....	...do.....	NA.....	66
15	...do.....	...do.....	...do.....	...do.....	Secs 2, 3, 10, and 11, T 36 N, R 49 E.	Bootstrap.....	Waste rock, dump..	NA.....	4
16	Placer Amex-Bunker Hill Cortez Gold.	...do.....	Lander....	Cortez.....	Sec 13, T 27 N, R 47 E.....	Cortez.....	Waste rock, heap..	NA.....	6
17	...do.....	...do.....	...do.....	...do.....	Sec 36, T 28 N, R 46 E.....	Gold Acres.....	Open pit, heap....	NA.....	NA
18	Occidental Minerals Corp.-Candelaria Partners.	...do.....	Mineral...	Candelaria....	Sec 5, T 3 N, R 35 E.....	Candelaria Project.	...do.....	8,000 ton/d.....	140
19	Smoky Valley Mining Co.-Copper Range Co.	...do.....	Nye.....	Round Mountain	Sec 18, T 10 N, R 44 E.....	Smoky Valley...	...do.....	7,000 ton/d.....	200
20	Golden Arrow, Inc.....	...do.....	Nye.....	Clark Station.	Sec 22, T 2 N, R 48 E.....	Golden Arrow...	...do.....	15,000 ton/yr...	9
21	D Z Exploration Co.....	...do.....	Pershing..	Rochester.....	Secs 28, 29, 32, and 33, T 29 N, R 34 E.	Nevada Packard.	...do.....	500,000 ton/yr..	5
22	American Selco-Occidental Minerals Corp.	...do.....	White Pine	NA.....	NA.....	Alligator Ridge	...do.....	680,000 ton/yr..	NA
23	Gold Creek Corp.....	...do.....	...do.....	White Pine....	Sec 19, T 16 N, R 58 E.....	Tresure Hill...	...do.....	50,000 ton/yr...	34
24	Challenge Mining Co.....	New Mexico	Catron....	Mogollon (Cooney).	Secs 32 and 33, T 10 S, R 19 W	Eberle, Confidence.	Open pit and waste rock, heap.	34,000 ton/yr...	4
25	Gold Fields Mining Co.....	...do.....	Santa Fe..	Old Placer (Ortiz).	Secs 19 and 20, T 13 N, R 8 E.	Ortiz Project..	Open pit, heap....	750,000 ton/yr..	48
26	Canorex Development[2].....	...do.....	NA.....	NA.....	NA.....	NA.....	...do.....	500 ton/d.....	NA

NA Not available.
[1]Data in table are from a pilot heap leaching operation; the company has decided to go to a conventional mill with the commercial operation instead of heap leaching.
[2]Presently inactive.

TABLE 3. - Ore mineralizstion and process characteristics

No.	Host rock	Mineralization	Ore grade, oz/ton		Ore prepa-ration: Particle size, in	Heap or dump dimensions				Influent solution					Applicstion		
						L, ft	W, ft	H, ft	Cspac-ity, ton	NaCN conc, lb/ton	pH	Alkalinity Control	Alkalinity Strength, lb/ton	Flow rate, gal/min	Method	Rate, gal/min·ft^{-2}	Interval, dsy
1	Limestone	Silver		NA	-3/16	200	600	NA	2,000	NA	NA	NA	NA	NA	NA	NA	14
2	NA	...do	2.0	Ag	[1]-1/2	NA	NA	6	6,000	5.0	NA	NA	NA	NA	NA	NA	7
3	NA	Cerargyrite	4.9	Ag	ROM	NA	NA	5	NA	1.0	10 - 11	NaOH	1.0	50	Rainbird sprinklers.	NA	NA
4	Disbase and grsnite	Native gold and pyrite.	0.05 - .1	Ag	-1	450	450	5	220,000	1.0 - 1.5	10 - 11	NA	NA	83	Holes in pipe; few rainbird sprinklers.	0.0006	21
5	NA	Free gold		NA	-1-1/2	NA	NA	7	NA	1.0	10.5	NaOH	NA	15- 20	Fixed sprays	NA	14
6	NA	Cerargyrite, bromyrite.	.0 -2.3	Ag	ROM (-4)	100	300	3	15,000	NA	13	...do	NA	50	Holes in pipe, rainbird sprinklers.	.01	90
7	Breccia (Miocene)	Native gold (oxidized tellurides).	.05	Au	ROM (-6)	NA	NA	15	NA	1.0	9 - 11	...do	.2	700	Rainbird sprinklers, double coverage.	.0025	56+
8	Flow breccia overlain by interbedded sandstones, shales.	Gold (oxidized)	.08	Au	-1	NA	NA		NA	NA	NA	NA	NA	NA	NA	NA	NA
9	Dolomite and limestone, Yellow Jscket Fm.	...do		NA	-1	300	300	15-20	45,000	1.0	11	NA	NA	NA	Sprinklers	NA	7 (21 wash)
10	Brecciated Greyson shsle, Spokane Fm. (Precambrian).	Gold	.068	Au	ROM (80 pct -6)	150	300	10	40,000	.3 - .5	10.5- 11	NA	NA	140	Rainbird sprinklers, 50-ft centers.	.003	90
11	Shear zones in syenite	Native gold, silver.	.325- .5 .032- .06	Ag Au	ROM (-24)	Var.	Var.	30-60	500,000	1.5	10.5	CaO	NA	400	Sprinklers	.005	15- 30
12	...do	...do	.027- .055 .266- .896	Au Ag	ROM (-24)	Var.	Vsr.	30-60	80,000-300,000	1.5	10.5	CaO	NA	800	...do	.005	NA
13	Sandy dolomite, Hamburg Fm. (Csmbrian).	Gold	.028- .04	Au	ROM	500	300	35	310,000	.8 - 1.0	8+	Self-induced.	NA	150	Ponding	NA	NA
14	Limey shales and siltstones, Roberts Mountain Fm. (Silurian).	Gold, mercury	.06 - .07	Au	-3/4	75	90	5	NA	.25	11.5	Lime	NA	450	Bagdad wigglers, 10-ft spacing.	.05 - .1	NA
15	Brecciated limestone and shsle, Roberts Mountain Fm. (Silurian).	Gold	.028	Au	ROM	NA	NA	60	NA	NA	NA	NA	NA	NA	Rainbird sprinklers.	NA	NA
16	Limestone, Roberts Mountain Fm. (Silurian).	...do	.05	Au	ROM	NA	NA	20	NA	.4	9.5- 10.5	NaOH	NA	500	Rainbird sprinklers, 50-ft spacing.	NA	NA
17	Brecciated limestone and shale, Roberts Mountain Fm. (Silurian).	...do	.05	Au	ROM	350	450	20	170,000	.6	10.5	...do	NA	550	...do	.025	NA
18	Candelaria shale-sericitized and argillized (Lower Triassic).	Argentite, argentojarosite.		NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
19	Welded rhyolite tuff (Miocene)	Gold	.045	Au	-3/8	425	250	12-14	50,000-65,000	1.0	11.5	NaOH	2.0	2,200	Bagdad wigglers, 36-ft centers.	.003 - .004	42
20	Andesite and rhyolite	Gold, silver	.08	Au	ROM	300	200	10	30,000	2.0	10 - 11	...do	1-2	NA	Rainbird sprinklers.	NA	14
21	Rhyolite	Argentite, cerergyrite	1.7	Ag	[1]-5/8	700	200	15	75,000	2.0	10.5- 11	Lime	NA	60- 75	...do	Vsr.	Intermittent.
22	Silicified siltstone	Submicroscopic gold.	.12	Au	[1]-0.075	NA	NA	12	NA	NA	NA	...do	.1	NA	Senninger wobblers.	NA	30- 40
23	Limestone over shale	Silver chloride		Var.	-1-1/4	250	225	8-15	25,000	2.0	10 - 11	NaOH	1-2	400	...do	NA	180
24	NA	Gold, silver	.045- .08 2.5 -4.5	Au Ag	-1/4	NA	NA	12	NA	NA	10 - 11	NA	NA	NA	Sprinklers	NA	60- 80
25	Brecciated quartzite with pyrite and limonite.	Gold, minute amount of silver.	.05	Au	-3/8	1,600	230	15	150,000	1.4	10.5	Lime	NA	NA	...do	.005	50
26	Quartz sinter	Gold, silver	.23 - .33 .63	Au Ag	ROM -3	20	20	30	10,000	2.0	12	NaOH or lime.	1.4	30	Pipes and lawn sprinklers, 60 full-jet steel nozzles.	.075	20

NA Not available. ROM Run of mine. Var. Variable. [1]Agglomerated.

TABLE 4. - Leach solution treatment

No.	Effluent solution				Mineral extraction								
	Leach solution grade, oz/ton	Solution loss	NaCN consumed, lb/ton	NaOH-CaO consumed, lb/ton	Recovery technique	Zinc activity booster	Charcoal loading, oz/ton	Charcoal stripping-precipitate dissolving	Electrowinning configuration	Voltage, V	Current, A	Metal recovery, pct
1	NA	NA.....	NA	NA	Zinc precipitation.	NA.....	NA	NA.....	NA.....	NA	NA	50
2	NA	NA.....	NA	NA	...do.....	NA.....	NAp	Directly smelted....	NAp.....	NAp	NA	90
3	0.3 -1.0	NA.....	0.5	NA	...do.....	NA.....	NAp	NA.....	1 cell, 3 by 1 by 1 ft.	NA	NA	35 Ag, 50 Au
4	.01 - .03	20 to 30 gal/min.	.5	5.0	...do.....	Lead acetate	NAp	NA.....	NA.....	NA	NA	40-50 Au
5	.016	10 to 15 pct.	NA	NA	Charcoal adsorption	NA.....	150	NaOH + 20 pct methanol.	1 cell.....	NA	30	35 Au
6	NA	NA.....	.1	.05	Zinc precipitation.	NA.....	NA	Nitric acid.....	NA.....	NA	NA	100 oz/d
7	.05	100 gal/min.	1.2	2.0	Charcoal adsorption	NAp.....	50-100	Ethanol and NaOH....	Downing design..	6.0	125	50 Au
8	NA	NA.....	NA	NA	...do.....	NAp.....	NA	NA.....	NA.....	NA	NA	NA
9	NA	15 to 20 gal/ton.	NA	NA	...do.....	NAp.....	NA	Hot caustic.....	NA.....	NA	NA	NA
10	NA	30 pct....	NA	NA	...do.....	NAp.....	NA	NaOH at 220° F × 90 psi (shipped to Cortez operation).	5 cells, 30 in^2 each.	3.5	100 (20 per cell)	50
11	.05 - .08	Var.....	.3	2.0	Zinc precipitation.	Lead acetate	NAp	NA.....	NA.....	NA	NA	25-40 Ag, 65-80 Au
12	.08 - .25	Var.....	.3	2.5	...do.....	...do.....	NAp	NA.....	NA.....	NA	NA	25-40 Ag, 65-80 Au
13	.007- .1	80 ton/d..	.5	NA	Carbon adsorption..	NAp.....	Up to 350	10 pct alcohol at 155° F.	NA.....	3.5	160-200	85 Au
14	NA	10 pct....	.1	1.0	Zinc precipitation.	NA.....	NAp	Directly smelted....	NA.....	NA	NA	60 Au
15	NA	NA.....	NA	NA	Carbon adsorption..	NAp.....	NA	20 pct alcohol.....	NA.....	NA	NA	NA
16	NA	15 to 20 pct.	NA	NA	...do.....	NAp.....	400	NaOH at 220° F × 90 psi.	5 cells.....	3.5	100 (20 per cell)	65 Au
17	.021	30 pct....	.45	.41	...do.....	NAp.....	400-500	1 pct NaOH at 240° F × 60 psi.	2 tanks; each 3.5 by 3 by 3 ft in parallel.	2.5	22.5	50 Au
18	NA	NA.....	NA	NA	NA.....	NA.....	NA	NA.....	NA.....	NA	NA	NA
19	.020- .030	5 pct.....	.60	.40	Charcoal adsorption	NAp.....	250	NaCN-NaOH at 180° F.	3 cells in parallel, 28 by 36 in.	3	70	60-70 Au
20	1.0	NA.....	NA	NA	Zinc precipitation.	Lead acetate	NAp	Precipitate cast in another facility as doré bars.	NAp.....	NAp	NAp	NA
21	Var.	30 pct....	.5	Minor	...do.....	Lead nitrate	NAp	NA.....	NA.....	NA	NA	58 Ag
22	NA	NA.....	NA	NA	Charcoal adsorption	NAp.....	NA	NaCN-NaOH.....	NA.....	NA	NA	80 Au
23	1.0	5 pct.....	.125	NA	NA.....	Lead acetate	NAp	Cast as doré bars...	NAp.....	NAp	NAp	65 Ag
24	NA	NA.....	NA	NA	Add Na S to precipitate for Ag, then C adsorption for Au.	NAp.....	NA	1 pct NaOH, 0.1 pct NaCN, 20 pct alcohol.	NA.....	NA	NA	69 Ag, 82 Au
25	NA	NA.....	1	6	Carbon adsorption..	NAp.....	250	1 pct NaOH, 0.1 pct NaCN, 5 pct alcohol.	2 cells each with 18 cathodes.	6	350-400 per cell	85
26	NA	NA.....	.4	2.9	...do.....	NAp.....	300 Au 300 Ag	Smelted and refined (American Smelting and Refining Co.).	NA.....	NA	NA	90 Au, 70 Ag

NA Not available. NAp Not applicable. Var. Variable.

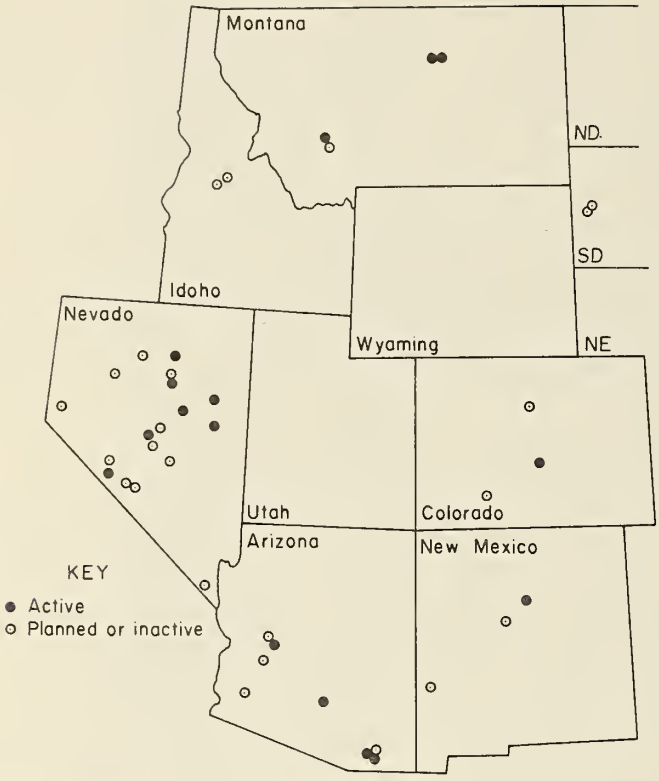

FIGURE 12. - Leaching operation locations in the United States.

ARIZONA

Arizona has been second only to Nevada in hosting solution mining operations. The latest figures show that 14 operations had been strongly considering heap leaching (table 1), and 6 of these have provided enough data to warrant inclusion in tables 2 to 4.

A heap leaching operation has been established near the Congress Mine shafts, which originally supported underground gold mining. Rock from the waste-rock dumps is being crushed and hauled to the leaching pad, where three separate heaps are being leached. After rock from the original waste piles is exhausted, the company is considering opening another underground mine adjacent to the existing shafts to provide ore for leaching.

Near Tombstone, the State of Maine Mining Co. has established an operation at an old underground silver mine of the same name (17). Feed for the heaps is obtained from waste rock dumps from the original operations. Plans are being made to resume underground mining to obtain new ore when the dump material is exhausted. The material will probably be crushed to boost the recovery. The State of Maine Mining Co. also manufacturers small zinc-precipitation processing plants for leaching operations.

At the nearby Contention Mine (also including the Grand Central and Flora Morrison Mines), Tombstone Exploration, Inc., is removing overburden and mining low-grade ore over the original underground working (16). Most of the rock can be mined by scrapers after it is ripped with bulldozers. The rock is crushed and presoaked with cyanide solution before being agglomerated into low-strength pellets. Pellets are formed by a unique inclined conveyor designed by the company. The material is then placed on a pad for leaching in 6,000-ton heaps (5×10^6 kg). Geologic investigations have delineated ore for at least 20 yr of operation.

Between the State of Maine Mine and the Contention Mine, Can-American Mining Co. is operating a leaching system for silver at the Dry Hills Mine. Although most of the leach material has been obtained from old mining waste rock, underground development is underway to provide new ore for the heaps. Ore is crushed to minus 3/16 in (0.5 cm) before being loaded on the heaps. The recovery averages 50 pct after 2 wk of leaching in spite of manganese contained in the ore.

Also near Tombstone, Silver Ridge Mining Co. has conducted heap leaching tests on ore from the old Nicholas and Gambasino Mines. The leaching tests were not promising because the manganese makes the silver somewhat refractory, and poor solution percolation occurred in the test heaps. Consequently ore will be processed in conventional mills.

In the late 1970's, Minerals 71, Inc., trucked dump material from several silver mines around Tombstone to its site for heap leaching. A million-ton (0.9×10^9 kg) heap was apparently leached

for 3 yr before production stopped. Since the operation shut down in February 1979, engineering data are currently unavailable.

Vekol Mine Development Co. has established a heap leaching operation adjacent to the Vekol Mine, an old underground silver mine located on the Papago Indian Reservation south of Casa Grande. Rock from mine dumps is placed on a prepared pad for leaching. This operation has been on-line since 1978. A pad with a capacity to hold 25,000 tons (23×10^6 kg) of ore is being prepared for heap leaching of an exposed silver ore body that crops out near the adit of the original mine. About 3 to 5 million tons (2.7 to 4.5×10^9 kg) of ore could be removed from this ore body by surface mining.

Near Humboldt, an experimental heap leaching pad was established at the Little Jessie Mine adjacent to its waste rock dump. The rock was placed on the heap without crushing. The grade of the return solution never reached an acceptable concentration even when it was merely recycled. Part of the problem may have been that the high clay content in the rock (due to disintegration of the schist) caused channeling. Another reason may have been that the pyrrhotite exhausted the cyanide. No further leaching activities are planned.

East of Salome an experimental operation was established on the Robinson Claims at the site of an opencut gold mine that had been located near old underground mines. Rock in and around the pit was reconstituted into a 4,000-ton (4×10^6 kg) heap for an experiment where leaching was carried out over several months to determine leaching parameters and to test equipment. Plans are being made to start blasting and hauling ore from the opencut for a commercial operation.

At the site of the old San Marcos gold mine, east of Wenden, a small leaching operation has been established. Dump material from the mine was placed on a small pad and leached. An experiment was carried out to determine the amenability of the ore to agglomeration. Results of the experiment look promising, and plans are being made to expand the work.

Several other operations that considered leaching but have not provided engineering data or have closed before significant engineering data could be gathered include the Montana Mine near Ruby, the King Tut Mine, the Pope Mine near Willow Beach, the Octave Mine near Yarnell, and several mines around Oatman.

CALIFORNIA

Although much gold has been mined in California, most has been recovered from placers by dredging, hydraulic mining, sluicing, and panning. Solution mining is noticeable by its scarcity. Only a leaching operation run by Chemgold at the Picacho Mine north of Yuma, AZ, could be located. At that operation, ore is placed in successive lifts on one big pad and solution is applied by "ponding." Gold Fields Mining Corp. has discovered a possibly leachable deposit--called the Mesquite deposit--in Imperial County, but no tests have yet been run. In addition, Anaconda has conducted agglomeration and leaching tests on tailing from the Darwin Mill, Inyo County.

COLORADO

The solution mining industry is not so well developed in Colorado as it is in Arizona and Nevada; only the Gold Resources-Newport Minerals Inc. operation provided enough data for inclusion in the engineering tables.

Since about 1976, the Gold Resources-Newport Minerals Inc. joint venture has operated an open pit mine-heap leaching complex on Globe Hill. Although many of the Cripple Creek deposits are telluride (and hence not amenable to direct cyanide leaching), this mine is in an oxidated zone of the breccia from the Cripple Creek volcano. A 10,000-ton/d (9×10^6 kg/d) mine supplies ore for heaps. The ore is blasted using 5-5/8-in (14-cm)

blastholes on 10-ft (3-m) centers and is leached as run-of-mine. Leaching operations extend from May to November.

Texasgulf, Inc., joined Golden Cycle Corp. in a 3-yr, $3 million exploration program (29) to evaluate gold mining potential of Golden Cycle's properties around Victor. One of the projects was to renovate and explore the underground Ajax Mine. The work was interesting because of the plan to try in situ leaching with chloride and iodine solutions for the telluride minerals. Since the mine follows a very steeply dipping vein structure, it was hoped that the leach solution could be applied through horizontal drill holes following the vein's strike and collected in basins prepared in the drift after flowing down through the fracture system (fig. 13). Problems in dissolving the telluride gold ores and in collecting the pregnant solutions caused the experiment to be abandoned in 1979. The companies recently announced plans for conventional mining and milling ore from the Ajax Mine.

Dreco Mines, subsidiary of Southern Cross, Ltd., conducted a 9,000-ton (8×10^6 kg) heap leaching test between Del Norte and Torres in the eastern San Juan Mountains during 1981. Permits are being acquired for a 1,500-ton/d (1.4×10^6 kg/d) open pit mining-heap leaching operation. Another heap leaching test was conducted by E & B Mining near San Luis during the summer and fall of 1982. It is not known whether the company plans a commercial operation.

Exploration drilling for ore body delineation has been conducted at the Gold Ray Mine between Copper Mountain and Mineral Hill (30). Favorable ore for leaching has been discovered; this ore is oxidized into free gold, unlike the usual Cripple Creek area tellurides. A leaching plant was constructed for assembling at the site.

Yellow Gold of Cripple Creek, Inc., has adopted plans to explore the Rittenhouse Mine and refurbish various drifts and shafts (32). Part of the plan calls for

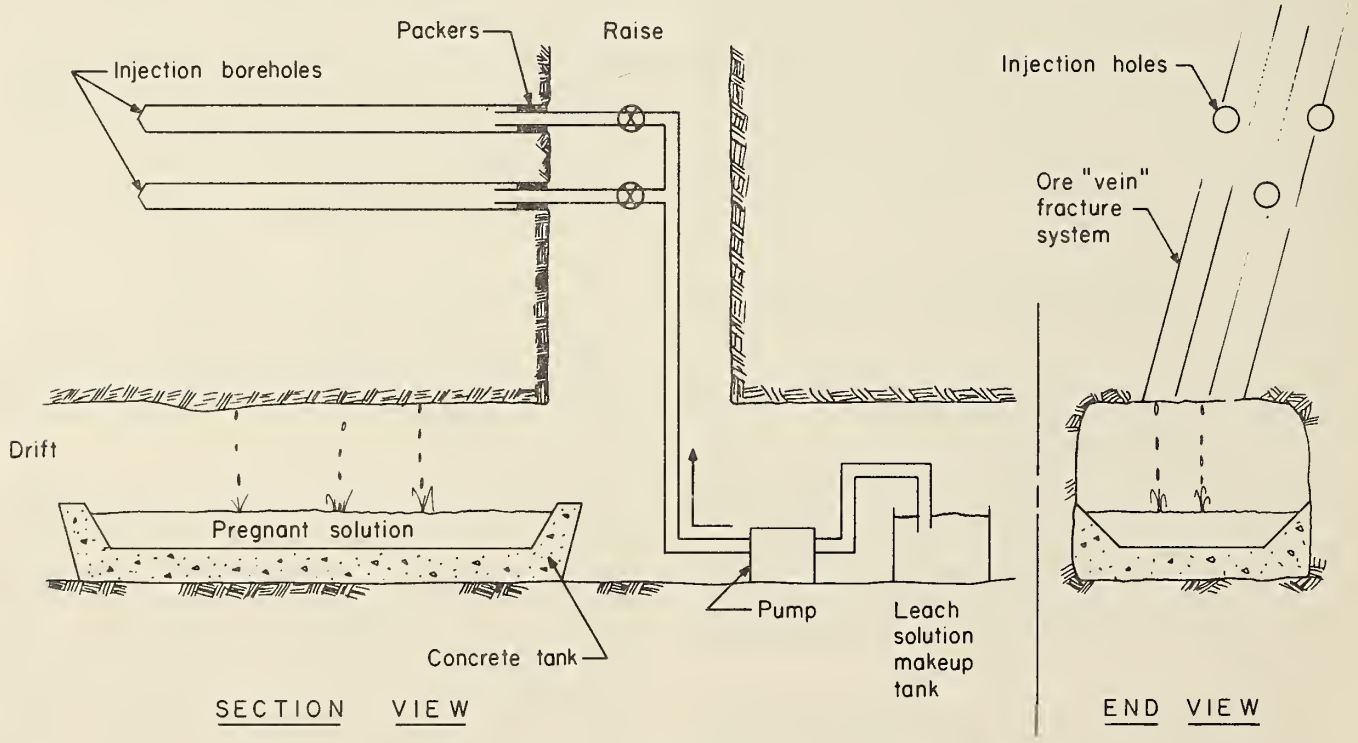

FIGURE 13. - In situ leaching test at Ajax Mine.

heap leaching the material in two mine dumps located on the property. It is not known if tests have been conducted on the material.

Recent news articles have publicized the work at Saratoga Mines' sites near Central City. No further information is available at this time.

IDAHO

Several operations in Idaho have conducted tests on the heap leaching potential of lean ore in and around previous mining districts. Information on these tests and any full-scale activities resulting from them has been very scant; only two are discussed.

Canadian Superior Mining, Ltd., has been conducting experimental heap leaching of ores from the Stibnite area since 1974. Although the Yellow Pine Mine was originally an open pit operation for antimony and tungsten, gold was encountered at one end of the pit. Recent drilling has delineated two nearby ore bodies--the West End and the Garnet Creek--that appear favorable for leaching. In the fall of 1978, Canadian Superior conducted a 500-ton (0.45×10^6 kg) heap test on crushed ore; two other tests were conducted during the summer of 1979. These tests led to a leaching plan whereby the ore would be mined from two open pits, placed into 45,000-ton (41×10^6 kg) heaps, and leached. Production began late in 1982 after completion of an Environmental Impact Statement by the U.S. Forest Service.

Canadian Superior had also obtained the rights to explore and develop a gold mining property owned by Thunder Mountain Gold, Inc., in the Thunder Mountain district near McCall (31). After Canadian Superior terminated its agreement with Thunder Mountain, a new agreement was reached with Phillips Petroleum for developing the property with Coeur d'Alene Mines Corp. as the operator. The gold apparently occurs at a shallow depth that would permit open pit mining. The operation would probably be patterned after plans developed for the proposed operation in nearby Stibnite, where ore would be heap-leached and recovered by charcoal adsorption.

MONTANA

Heap leaching for gold and silver is rapidly emerging in Montana. Of the several operations that have expressed interest, 2 have reached full commercial production, and 1 is conducting large-scale field tests.

The two operations are on opposite sides of a peak in the Little Rocky Mountains (15, 6). Landusky Mining, Inc., and Zortman Mining, Inc., are both owned by Pegasus Gold, Ltd. One mine is a few miles north of Landusky near the old August and Gold Bug Mines. An open pit mine produces 24,000 ton/d (22×10^6 kg/d) to supply the heaps. Blastholes are drilled on a 10- by 8-ft (3- by 2-m) pattern to depths of approximately 40 ft (12 m). The other mine is north of Zortman near the old Ruby Gulch Mine. Here two open pits produce 17,000 ton/d (15×10^6 kg/d) of ore. Blastholes are on an 8- by 8-ft (2- by 2-m) pattern. Together the two operations were estimated to contain 50 million tons of reserves at ore grades favorable for heap leaching and are annually producing 40,000 oz (1.2×10^6 g) of gold and 90,000 oz (2.8×10^6 g) of silver.

The Golden Sunlight Property 6 miles east of Whitehall hosted extensive underground mining for gold through the early 1950's. As part of its Heavy Metals Program, the Bureau of Mines and other agencies conducted detailed economic analysis of conventional mining on the property (1). The present operator, Placer-Amex, first experimented with leaching on a 26,000-ton (24×10^6 kg) test heap. The heap was segregated into five segments (each containing a different size distribution of ore) that provided solution for five separate charcoal adsorption units. The heap was then expanded to 40,000 tons (35×10^6 kg) for a full production test. Feed for this effort was run-of-mine rock. High clay

content in the ore caused percolation troubles; the heaps had to be periodically ripped. These troubles led to a recent decision to construct a conventional mill complex for processing the ore. Heap leaching has been dropped from immediate consideration.

In 1978 a heap leaching test was carried out on ore from the Tourmaline Queen Mine east of Boulder. Approximately 25,000 tons (23×10^6 kg) were satisfactorily leached. A 30,000-ton (27×10^6 kg) heap was constructed, and caustic was added for a new test to be conducted when the snow melted in the spring of 1979. When this test also proved successful, ore was obtained from an open pit mine for a commercial-scale heap. Since recovery from this heap was lower than anticipated, the ore was crushed and replaced on the heaps for leaching in 1981. Approximately 3 million tons (2.7×10^9 kg) of ore graded at 0.07 oz/ton (0.024 g/kg) gold were delineated from open pit mining.

NEVADA

Nevada is currently the center of heap leaching activity. Numerous operations have been or are actively considering leaching. The Smoky Valley, the Cortez, and the several Carlin operations have all been well documented in mining literature. Enough data are available on 11 of these operations to warrant their inclusion in tables 2 to 4.

The Carlin Gold Mining Co. operation pioneered solution mining systems targeted for low-grade, disseminated, oxidized gold ore bodies. Commercial heap leaching operations began in 1971, following laboratory and pilot scale tests. About 10,000 tons (9×10^6 kg) of low-grade oxidized ore were leached each month between April and October. Four leaching pads were eventually placed in operation. Although the pads were generally leached about 7 days before replacing the ore, solutions were applied until their gold grade dropped below 0.015 oz/ton (0.005 g/kg). Although the ore from this mine is now processed in a conventional mill, portions of the ore body are amenable to future heap leaching (35). Exploration activities have uncovered two other ore deposits near the mine--the Maggie Creek and Gold Quarry Prospects--portions of which will probably be heap-leached. Contracts have been awarded to construct mining and heap leaching facilities at the Maggie Creek Deposit, and approximately 2.5 million tons (2.3×10^9 kg) of ore had been leached at the mine by the end of 1980.

Carlin also has been dump-leaching at the Bootstrap Mine north of its Carlin pit. The Bootstrap Mine was a surface operation from the late 1960's until 1978. A sizable waste rock dump on the property is being leached. The dump was originally placed on a compacted ancient lakebed, which makes an impervious pad suitable for leach solution containment. The dumps are merely leveled to facilitate solution distribution.

Numerous small, underground mines around Round Mountain produced gold from the turn of the century until the late 1930's. Now Smoky Valley has established an open pit mining and heap leaching operation near Round Mountain (25, 41). By 1977, the operation was producing 85,000 oz (2.6×10^6 g) of dore bullion per year consisting of two-thirds of gold and one-third of silver. To achieve this rate, about 8,000 tons (7×10^6 kg) of ore and 7,000 tons (6×10^6 kg) of waste rock are mined per day. The ore is crushed, placed on a pad, and leached in one lift. The spent ore is then rinsed and moved off the pad to make room for the next batch of ore. Five pads are in continuous operation; four are being leached and one is being reconstituted at any given time. Three new pads were constructed during 1980.

Another leaching operation that is well documented is Placer-Amex's Cortez Mine (13-14). The Cortez Mine opened as a surface operation for a conventional mill in 1969. Although the ore body was exhausted by spring of 1973, the mill continued to process ore trucked from the nearby Gold Acres Mine. During mining

operations, marginal ore (below mill grade of 0.08 oz/ton [0.03 g/kg]) was stockpiled. When tests run on this material indicated that it might be suitable, a heap leaching operation began in 1971. In 1976 the conventional zinc precipitation mill circuit was converted to an activated carbon adsorption system.

Placer-Amex also operated the nearby Gold Acres leaching operation. Although currently idle, the operation has been well publicized (13). The site of an early mine, Gold Acres was open-pit-mined beginning in 1973 to feed the Cortez mill as a replacement for the depleted Cortez Mine ore. When this operation proved successful, a new leaching plant was constructed at the Gold Acres site. It was one of the first, if not the first, commercial applications of the charcoal adsorption system in the country. The high clay content of Gold Acres ore created lower percolation rates and recoveries than were obtained from the nearby Cortez Mine. The clayey Gold Acres ore was not suitable for leaching from lifts placed on top of each other, and periodic ripping was needed to prevent ponding. Furthermore the ore was highly carbonaceous and thus very refractive below the oxidized zone. Although approximately 5 million tons (4.5×10^9 kg) of ore had been heap-leached at Gold Acres and Cortez by the summer of 1977, the only current plans center around leaching waste dump rock from the idle Gold Acres property. Cortez has also announced plans to develop the nearby Horse Canyon Deposit, but it is anticipated that conventional milling rather than heap leaching will be used.

South of Eureka, a heap leaching operation has been in production several years. Near the original Windfall Mine underground workings, Idaho Mining Co. has produced ore from an open pit mine to feed its heap leaching operation. The operation is one of two that uses a ponding technique for solution distribution on the pads (fig. 8). Ore is hauled from the mine to the pad area and stacked. Berms are laid out on the surface of the pad to control the solution flow. Since the ore is a sandy dolomite, essentially clay free, percolation rates remain acceptable. Idaho Mining also opened a new pit on the property in a zone that contains some clay. It will be interesting to see if adequate percolation can be maintained on ore from the new pit. In January 1980, Windfall Venture purchased the operation from Idaho Mining.

Occidental Minerals Corp. dedicated its Candelaria operation in November 1980. At one time many underground silver mines were operating in the Candelaria district. Two of these mines--Lucky Hill and Mt. Diablo--are being stripped and open-pit mined to provide feed for a large heap leaching operation. Although the overall ore grade is good, the manganese oxide content makes it somewhat refractory. A number of experiments were carried out at the site, ranging from 500-lb (200-kg) "barrel" tests up to a pilot heap leach on 11,000 tons (10×10^6 kg) of ore. Based on the successful pilot test, plans were made to mine the two deposits at a rate of 8,000 tons (7×10^6 kg) per day along with 16,000 tons (14×10^6 kg) per day waste rock. Stripping began in the spring of 1980, and the first silver was poured in the fall of 1980. In 1981, its first year of production. the operation produced 1.7 million oz (53×10^6 g) of silver and 9,200 oz (0.28×10^6 g) of gold. The company preferred not to disclose engineering data from this stage of development. In June 1982, the operation closed because of the decline in silver prices. In 1983 Nerco Metals bought Occidental Minerals and reopened the Candelaria operation.

American-Selco and Occidental Minerals combined on a successful heap leaching experiment on Alligator Ridge about 60 mi (96 km) northwest of Ely. First a 5,000-ton (4.5×10^6 kg) heap containing 0.18 oz/ton (0.06 g/kg) gold was leached for 2 months, with an 80-pct recovery. Next the same amount of ore was leached after the fines were agglomerated, following the Bureau's technique (see section on ore preparation), and the same recovery was obtained in only half a month. Following these successful tests,

construction began in the spring of 1980, and the operation is now producing about 60,000 oz (180,000 g) of gold per year.

D Z Exploration has been conducting experiments at the Packard Mine in an old silver mining district northeast of Lovelock for two seasons. The first experiments were on run-of-mine-sized material from the waste dumps. Since this material had weathered, enough fines were created to restrict percolation through the reconstituted heaps. Attention focused in 1979 on the Bureau's agglomeration technique as a means to improve percolation. To test the technique on this rock, ore was crushed to three sizes--2 in (5 cm), 7/8 in (2 cm), and 9/16 in (1.4 cm)--and agglomerated using 10 lb (4.5 kg) of cement per ton (90 kg) of ore. Cement was added to the crushed ore by a unique auger arrangement. Water spray was directed at the mixture, which then tumbled down an incline to complete the agglomeration. An 8-ft (2-m) high heap containing several hundred tons of each size material was then leached. Based on the results and additional drilling, full-scale production was expected to begin in 1981, but no updated information is available.

Pinson Mining Co. opened a major open pit mining and milling complex in Humboldt County during 1981 (39-40). Approximately 500,000 tons (0.45×10^9 kg) of material below the 0.05-oz/ton milling cutoff grade were stockpiled for future leaching. Pads were built in 1982 for several heap leaching tests involving agglomerated and unagglomerated ore, scale inhibitors, oxidizers, solution application techniques, etc. These pilot tests then formed the basis for designing a full-scale heap leaching facility that began operation in December 1982. Tests are now being conducted on material from the nearby Preble ore body.

Other operations that have been discussed by the mining press include the United Hearne Resources, Ltd., operation near Hamilton, the Getchell property recently purchased by First Mississippi Corp., the Bald Mountain property northeast of Ely, the Relief Canyon property being tested by Lacana Mining northeast of Reno, Dee Gold Mining Co.'s Boulder Creek property near Carlin, Gila Mines Corp.'s mine near Reveille, the Borealis Mine managed by Houston International Minerals Division of Tenneco, Inc., the Tuscarora operation that belongs to Tuscarora Associates, and the Gold Crown Mine in the Current Creek district operated by Great American Gold Co. The large number of leaching operations emerging in Nevada each year makes it impossible to accurately track all of them. Since this is not the purpose of the report, other Nevada operations are not discussed.

NEW MEXICO

Solution mining operations have been relatively rare in New Mexico; only three have been identified. One of these is now inactive, while two are currently producing gold. All three are listed in the engineering data tables.

Gold Fields Mining Corp. has brought the Ortiz Mine, 35 miles (56 km) southeast of Albuquerque, back into production with a heap leaching operation (22). The activity stems from a mining and leaching plan submitted in 1978 to the New Mexico Health and Environment Department. Ore is being produced from a 3,000-ton/d (2.7×10^6 kg/d) open pit mine, which is being dewatered by a series of peripheral wells. After the ore is crushed to less than 3/8 in (9.5 mm), it is placed on a pad with a traveling gantry system. Pebble lime is added to the ore to control pH yet minimize scale problems that are normally encountered when "milk-of-lime" is added to the makeup solution. Gold recovery has averaged 78 pct with a high of 87 pct since the operation opened.

During the mid-1970's interest revived in the old Cooney mining district around Mogollon. Mine dumps from the Confidence Mine and surface vein ore from the Eberle Mine were tested by Challenge Mining Co. for leachability with favorable results. The company has developed a 2-yr plan for heap leaching at a rate of 34,000 ton/yr

(31×10^5 kg/yr) (18). After 2 yr this material will be depleted, which will require underground mining in the old Eberle workings. An estimated 300,000 tons (0.27×10^9 kg) grading 4 oz/ton (1.4 g/kg) silver and 0.08 oz/ton (0.027 g/kg) gold remains in the mine.

In 1975, Canorex opened a 500-ton/d (450×10^3 kg/d) open pit gold mine to provide feed for a heap leaching operation (7). Two adits in the ore body had proven ore reserves of 1 million tons (0.9×10^9 kg), grading 0.23 oz/ton (0.08 g/kg) gold and 0.63 oz/ton (0.21 g/kg) silver. A plant was constructed to handle solution from the heaps. The operation apparently went well for a while but has not produced recently.

SOUTH DAKOTA

Two heap leaching operations have been identified in South Dakota. One functioned at the pilot-scale level in 1980; the other has applied for the permits necessary to construct a pilot facility.

Cyprus Exploration is operating the pilot-scale leaching test at the Gilt Edge property 4 miles (6 km) southeast of Lead in the Black Hills. At the site of early mining activity, a pad and solution ponds were constructed for a 1,900-ton (1.7×10^6 kg) heap. Further information is unavailable at this time.

Tiaga Gold Corp.-Wharf Resources, Inc., has delineated a 5-million-ton (4.5×10^9 kg) ore body at 0.04 oz/ton (0.014 g/kg) gold on their Anne Creek property 4 miles (6 km) southwest of Lead. Plans are being made to heap-leach the ore with a system patterned after the Zortman-Landusky operations in Montana.

PERMITTING REGULATIONS

FEDERAL REGULATIONS

The Resource Conservation and Recovery Act of 1976 (RCRA) has been the Federal regulatory action recently attracting the most attention from miners (34). Aimed at improving resource conservation and recovery through land use control, the act establishes a Federal-State permit system for hazardous waste management. Originally the mining operators were considered to be producers of hazardous waste and operators of hazardous waste treatment, storage, and disposal facilities. So many problems arose in attempting to apply the regulations to mining operations, however, that an amendment was passed in October 1980 to exempt mining from the law while studies were conducted. It is safe to assume, however, that this act will eventually impose some control. Since the material on a leaching pad and any leachate emanating from it could be considered hazardous wastes, leaching operations will fall under the purview of the act. Ground water monitoring programs will be required to assure that the uppermost aquifer will not be harmed. Although the U.S. Environmental Protection Agency (EPA) is charged with administering the permit and enforcement provisions of the act, EPA intends to pass on the permit system to the States.

EPA is also charged with implementing the Safe Drinking Water Act and, particularly interesting to in situ leaching operators, its Underground Injection Control Program. This program establishes a permitting system for five classes of wells by which fluids are injected or disposed into the ground. EPA also regulates surface discharge permits under the National Pollutant Discharge Elimination System (NPDES) and the Prevention of Significant Deterioration Program, which may affect a potential leaching system. Operators should contact the closest regional EPA office for clarification on permits required (table 5).

TABLE 5. - Environmental Protection Agency regional offices issuing hazardous waste and surface discharge permits

Office	Coverage	Office	Coverage
Region IV Enforcement Division 1st International Bldg. 1201 Elm St. Dallas, TX 75270 (214) 749-1983	New Mexico Texas	Region IX Enforcement Division 215 Fremont St. San Francisco, CA 94105 (415) 556-2320	Arizona California Nevada
Region VIII Enforcement Division Suite 900 1860 Lincoln St. Denver, Co 80203 (303) 837-3868	Colorado Montana North Dakota South Dakota Utah Wyoming	Region X Enforcement Division 1200 6th Ave. Seattle, WA 98101 (206) 442-1220	Idaho Oregon Washington

Leaching operations targeted for U.S. Forest Service, Bureau of Land Management, or other Federal lands will probably require an environmental assessment before permission to proceed is granted. A prospective operator should clear this through the district office of the Federal agency controlling the land. A helpful discussion of regulations and procedures is contained in "Forest Service Current Information Report No. 14," available at Forest Service offices.

In addition, recent Bureau of Land Management (BLM) regulations (43 CFR 3800) on Surface Management of Public Lands Under U.S. Mining Laws went into effect January 1, 1981, for the purpose of preventing undue degradation and requiring reasonable reclamation of BLM lands disturbed by any mining. Depending on the level of activity and size of the disturbance, a plan must be filed and sometimes approved by BLM before mining can proceed.

STATE REGULATIONS

Permits required for leaching vary considerably from State to State. Table 6 lists a few key permits and gives the associated State agencies to be used as initial contacts. These contacts can provide details on which permits are required and the regulations and requirements pertaining to each.

It is interesting to note that California and Colorado have moved toward consolidating permit requirements into one office. In California, the central contact is the Department of Economic and Business Development, which provides any new business venture with a complete list of necessary permits and directions for obtaining them. The county commissions assume leadership in California during the permitting process.

Colorado has developed a voluntary process, tailored primarily for large operations, whereby a company can request a Joint Review of a proposed mining project. If a company requests this Joint Review, the State coordinates interests of all involved Federal, State, and local agencies and develops a statement of responsibilities and problems that must be resolved and a schedule of activities during the regulatory time period. Companies that do not wish to use the Joint Review process may proceed as before, by interacting with the permitting agencies, a list of which can be obtained from the Colorado Department of Natural Resources (table 6).

For the other States where leaching is practiced, table 6 lists the prime agency contacts.

TABLE 6. - State permitting agencies

Agency	Action	Remarks
	ARIZONA	
Department of Natural Resources Mineral Bldg., Fairgrounds Phoenix, AZ 85007 (602) 255-3791 or State Office Bldg. 415 West Congress, Room 190 Tucson, AZ 85701 (602) 882-5399	Booklet on laws and regulations.	
State Mine Inspector 705 West Wing Capitol Bldg. Phoenix, AZ 85007 (602) 255-5971	Mining code and regulations.	Must be notified of commencement or suspension of operation. Regulates health and safety.
Bureau of Water Quality Control Arizona Department of Health 1740 West Adams Phoenix, AZ 85007 (602) 255-1252	Water discharge permit.	
Department of Water Resources 99 East Virginia Phoenix, AZ 85004 (602) 255-1550	New water supply permit.	
	CALIFORNIA	
Department of Economic and Business Development 1120 N St. Box 1499 Sacramento, CA 95805 (916) 322-1394	All necessary permits.	Provides all permitting information for any business.
	COLORADO	
Department of Natural Resources Executive Director's Office 1313 Sherman St., Room 723 Denver, CO 80203 (303) 839-3337	Joint review process.	The joint review process is an optional consolidated review procedure for major energy and mineral resource development projects.
	Colorado permit directory.	Operator may elect to obtain permit directory and deal with permitting agencies.
	IDAHO	
Department of Lands Bureau of Minerals State House Boise, ID 83720 (608) 334-3569	Mining permit.....	
Manager Source Control Section Water Quality Bureau Division of Environment Deapartment of Health & Welfare State House Boise, ID 83720 (208) 334-4059	Waste water treatment review.	Review, no permit.

TABLE 6. - State permitting agencies--Continued

Agency	Action	Remarks
	MONTANA	
Department of State Lands Reclamation Division Hard Rock Bureau Capitol Station Helena, MT 59601 (406) 449-2074	Operating permit...	If over 36,000 ton/yr and/or 5 acres disturbance; otherwise small mines' exclusion.
Department of Health and Environmental Sciences Water Quality Bureau Room 206 Cogswell Bldg. Helena, MT 59601 (406) 449-2406	Water discharge permit.	
	NEVADA	
Administrator Division of Mineral Resources Department of Conservation and Natural Resources Nye Bldg. 201 South Fall St. Carson City, NV 89710 (702) 885-4368	Mining permit.....	Also will provide a list of State and Federal permits required before a mining permit can be granted.
	NEW MEXICO	
Bureau Chief Health and Environment Department Environmental Improvement Division Water Pollution Bureau Box 968 Santa Fe, NM 87503 (505) 827-5271	Ground water quality permit.	Administer the Water Quality, Control Commissions regulations.
	SOUTH DAKOTA	
Land Management Specialist Department of Agriculture Conservation Division Surface Mining Program Anderson Bldg. Pierre, SD 57514 (605) 773-4201	Reclamation permit.	Lead agency; coordinates input from other agencies.
Department of Health Division of Environment and Health Joe Foss Bldg. Pierre, SD 57514 (605) 773-3361	Solid waste disposal permit.	
Department of Water and Natural Resources Division of Water Quality Joe Foss Bldg. Pierre, SD 57514 (605) 773-3351	Water quality permit.	

LEACHING PROBLEMS AND RESEARCH

PERCOLATION

Several problems hamper broader application of leaching methods for recovering gold and silver. A prime problem is the predominance of silt- and clay-size particles in some ores that prevent uniform leaching solution percolation through the ore heaps. A high clay content will cause ponding and/or channeling, which blocks much of the ore from contact with the solution. Since small particles leach faster and more thoroughly than large ones, operators frequently crush the ore before leaching. Unfortunately crushing also can produce the extremely fine sizes that promote blockage and channeling. Even without crushing, some ores have a strong tendency to disintegrate into clay through natural weathering agents and/or action of leaching solutions. Tests should be run on the ore to determine the percolation rate and metal recovery for various size distributions.

Bureau of Mines research on agglomeration techniques provides the most promising solution to clay problems; this was described in the section on Leaching Operations and in references 27 and 28. The several operators who have tried this technique have observed rather spectacular inceases in percolation and recovery rates. Tombstone Exploration's Contention Mine agglomerates its ore, as do the Alligator Ridge, Packard, and Candelaria operations.

An extremely low permeability (tight) matrix presents a problem to leaching operators, again because the solution cannot reach the minerals. Weathered and oxidized ores generally leach better than unoxidized ones because oxidation breaks down an impermeable matrix. Heavier powder factors during mining may fracture the ore better, increasing the solution's access. A fresh, tight ore may, however, yield its values only if it is crushed and ground to a small enough size to expose the metallic mineral grain. Crushing and in particular grinding, however, greatly boost the costs of preparing the ore for leaching. As previously mentioned, it is imperative that laboratory tests be conducted to determine the most economical crushing size range.

TEMPERATURE

Solution temperature is a significant factor in leaching reactions. The chemical reaction between gold and silver and cyanide proceeds much faster in warm solutions. Below 10° C (50° F) the reaction is appreciably slower than it is at normal summer operating temperatures. In practice, however, most operators work in cold weather until the solutions begin to freeze. Depending on its location, a mine can lose several months per year of potential leaching time in cold weather.

A successful research program on methods to heat solutions for leaching would provide a valuable improvement in the technology. A solar heating system would seem to be an ideal candidate since most leaching operations are located in arid regions with little cloud cover. Saline evaporation ponds may also be a possible source of heat for leaching solutions.

The only reported research on solution heating is by Smoky Valley at its Round Mountain operation, where a 25-million-Btu/h (7.3-million-W) submersible kerosine heater installed in the leach solution pond has proven successful (26).

SOLUTION LOSS

At most leaching sites, 10 to 25 pct of the leaching solution is lost by evaporation. Since the leaching solution must contain high oxygen levels and since this is most easily achieved through spraying, evaporative losses seem inevitable. Important research topics would be to determine this loss and to measure dissolved oxygen in solutions as a function of the application method.

Besides the evaporative losses, gangue minerals in the ore consume both the

cyanide and the lime or caustic soda. Consumption may run as high as 25 to 50 pct. Since the interactions between cyanide solutions and most gangue minerals are well established, no new research is recommended for cyanide leaching. For those deposits that exhibit high cyanide consumption, research on alternative lixiviants may be warranted.

CALCIUM SALT SCALE

Calcium salts in distribution lines pose a major problem with most systems, particularly those that use lime for alkalinity control. At least one operation also experienced problems with barium salts clogging spray nozzles. The mineral scale prevents operators from using some small-orifice components in their distribution systems, such as the drip irrigation tubes used in copper leaching operations, and is particularly troublesome in sprinklers; frequent soaking in hydrochloric acid is about the only cure. Several operators mix a scale inhibitor, such as the Surfo-H35 organic phosphate marketed by Baroid, with the leaching solution to keep the calcium minerals dissolved. Some additives, however, occasionally form colloidal suspensions that plug filtration systems.

Bagdad wigglers, first used to distribute solutions at the Bagdad copper mine, offer a possible means to combat calcium salt scale. Simple to construct (fig. 7), the large-diameter tubing will remain open much longer than the small orifices of oscillating sprinklers and is easy to free from lime scale.

Many operators have experimented with NaOH instead of lime to control pH with considerable reduction in the rate of lime scale. The relative costs must be carefully weighed, however, since NaOH is more expensive.

RESEARCH ON NOVEL SOLUTION MINING METHODS

The Bureau of Mines has actively investigated new techniques in recovering and processing of gold and silver ores. Principal efforts have been directed toward the subeconomic, lower grade ores that are unminable and/or untreatable using traditional methods. Although major gold and silver projects have been investigated by various Bureau Research Centers, most current activity is concentrated at the Reno and Twin Cities Research Centers.

In Situ Leaching

In situ (in-place) leaching offers attractive benefits for producing metals at a minimum of capital investment and operating cost, with low environmental degradation. The technique has not been applied to gold and silver ores, primarily because of fear over public reaction to using cyanide solutions where ground water contamination is possible. Only one operation is known to have experimented with in-place gold and/or silver leaching, and that was with a noncyanide leach in an old underground mine. (See section on Colorado operations.) In this mine it was theorized that solutions could be injected into the fracture zone comprising the "vein" and that these solutions would migrate down the zone to drifts where they could be collected. To test the theory, water was injected into the vein and collected in a drift in a poured concrete trough (fig. 13). The experimenters concluded that the trough (and drift) were not wide enough to encompass the vein-fracture system; excessive solution losses occurred when the trough was bypassed. The experiment was never expanded to verify this conclusion because other metallurgical laboratory tests failed to resolve the chemistry of leaching that particular ore.

Several companies have expressed a willingness to try leaching gold and silver in-place. Successful commercial leaching operations for uranium and copper have demonstrated that in-place leaching is economically feasible and environmentally safe. If a system can be developed for in-place-leaching gold and silver that will be publicly acceptable, small and/or low-grade deposits can be mined more cheaply and easily than

previously possible. The Bureau of Mines Twin Cities Research Center recently funded a contract study to evaluate the feasibility of such a system and to develop a conceptual design for it. The most likely system involved blasting via vertical holes drilled from the surface to fragment shallow ore bodies, followed by solution application from the surface (36). After the solution percolated down through the fragmented ore, it could be pumped to the surface from vertical recovery wells or from underground solution collection drifts. Such a system would have a very good discounted-cash-flow return on investment with payout of less than 1 yr.

Underground mines offer potential for in situ leaching. Ore would be blasted and left in stopes for leaching. After percolating through the rubblized ore, pregnant solution would be pumped to the surface for extraction of the metals.

Placer deposits offer intriguing possibilities for in-place leaching, and several years ago the Bureau conducted laboratory tests on cyanide placer deposits (33). At some future date it is reasonable to assume that placers could be leached by vertical injection and recovery wells like those used for uranium in roll-front deposits.

Leach Farming

A patent granted in 1973 (23) describes a technique for leaching friable exposed ore bodies in place or conventionally mined ore that is placed in extremely shallow heaps. With this technique the ore is cultivated with standard farm equipment to loosen it to a depth of 6 to 12 in (15 to 30 cm). Leaching solution is added to the loosened ore, which is periodically cultivated and kept moist for the next several days. This cultivation assures uniform contact between leaching solution and the ore and prevents downward escape of the solution.

The leached ore, which still contains the pregnant leaching solution, is pushed by bulldozer or front-end loader to a sluice box where it is slurried and pumped to a settling pond. After the spent ore has settled in the pond, the pregnant solution is pumped from the pond to a recovery plant for removing the metals. Meanwhile, the next layer of ore is being cultivated as the cycle begins again.

Although the field experiments to verify this method were not conducted on gold and silver ores, laboratory experiments on them and field experiments on other ores worked well.

Thin-Layer Leaching

Thin-layer leaching, somewhat a variant of the leach farming method, was developed for the copper mines of South America (3-4). It offers potential for leaching gold and silver ores, particularly if combined with the Bureau's agglomeration process.

The first step in the method involves crushing the ore; minus 1/2 in (1.2 cm) was sufficient for the copper ores tested. Next, a concentrated leaching solution is mixed with the ore in a rotating drum until the ore contains 10 pct of solution. The ore is then placed in piles while the solution reacts with the ore. After 24 h the ore is transported to an impervious pad, where it is spread out in layers approximately 3 ft (1 m) deep. The ore is then sprayed with dilute leaching solution and/or water until the dissolved metals are rinsed out. This rinse solution is collected in ponds in the same manner as with any other heap leach and then pumped to a recovery plant for metals extraction. The damp tailing is then removed from the pad and piled in the disposal area.

SUMMARY

Gold and silver leaching operations have blossomed in many mining districts of the Western United States. Most are associated with old "vein" mines where the elements were deposited in fractures near volcanic or other igneous activity. A few large operations have also been established on oxidized sedimentary deposits containing very fine, disseminated gold.

In surveying current operations, over 80 were found that had conducted tests or were actively leaching on a commercial scale. Sufficient engineering data were obtained for 26 of these operations to justify their inclusion in tables that cover location, geology, heap configuration, influent solutions, effluent solutions, and extraction.

One of the first problems encountered by a hopeful leaching operator is obtaining the necessary permits from Federal, State, and frequently local agencies. To provide a start, key Federal and State agencies are identified in tables 5 and 6.

The main problems hampering leaching operations are unfavorable mineralogy and poor solution percolation owing to high clay content. Cold temperature effects on gold and silver solubility and rapid lime buildup in the distribution system also severely hamper the operations. Recent and ongoing Bureau research and continued work at various mining operations are helping improve the techniques.

REFERENCES

1. Ageton, R. W., G. T. Krempasky, and W. L. Rice. A Systems Approach to Recovering Gold Resources in Jefferson County, Mont. Introductory Review. BuMines RI 7305, 1969, 16 pp.

2. Barsky, G., S. J. Swainson, and N. Hedley. Dissolution of Gold and Silver in Cyanide Solutions. Trans. AIME, v. 112, 1934, pp. 660-677.

3. Brimm, E. O. Thin-Layer Leaching of Copper Ores. Pres. at AIME Annu. Meeting, New Orleans, LA, Feb. 20, 1979, 18 pp.; available from Holmes and Narver, Inc., 999 Town & Country Rd., Orange, CA 92668, as publication HN 0953.02.

4. Brimm, E. O., and P. H. Johnson. New TL Leaching Process. Pres, at Conf. of Metallurgists, Montreal, Quebec, Aug. 28, 1978, 22 pp.; available from Holmes & Narver, Inc., 999 Town & Country Rd., Orange, CA 92668, as publication HN 0953.00.

5. Buttermann, S. C. Gold. BuMines Mineral Commodity Profile, 1978, 17 pp.

6. California Mining Journal. Gold Reserve Corporation Reports Increasing Profits From Montana Mine. V. 51, No. 12, 1982, p. 4.

7. Chisolm, E. O. Canadians Operating Gold Leaching Operation in New Mexico. The Northern Mines, v. 61, No. 27, 1975, pp. 59-60.

8. Clevenger, G. H., and M. H. Caron. The Treatment of Manganese-Silver Ores. BuMines Bull. 226, 1925, 110 pp.

9. D'Andrea, D. V., P. G. Chamberlain, and J. K. Ahlness. A Test Blast for In Situ Copper Leaching. Pres. at 1978 AIME Annu. Meeting, Denver, CO, Feb. 28-Mar. 2, 1978, SME Preprint 78-AS-112, 6 pp.

10. D'Andrea, D. V., W. C. Larson, L. R. Fletcher, P. G. Chamberlain, and W. H. Engelmann. In Situ Leaching Research in a Copper Deposit at the Emerald Isle Mine. BuMines RI 8236, 1977, 43 pp.

11. Denver Equipment Co. (Denver, CO). Cyanidation of Gold Ores. Bull. M3-87, 1978, 8 pp.

12. Dorr, J. V. N., and F. L. Bosqui. Cyanidation and Concentration of Gold and Silver Ores. McGraw-Hill, 2d ed., 1950, 511 pp.

13. Duncan, D. M. Open Pit Gold Mining at Cortez. Ch. in Colorado Mining Association 1974 Mining Yearbook. Colorado Mining Association, Denver, CO, 1974, pp. 92-94.

14. Duncan, D. M., and T. J. Smolik. How Cortez Gold Mines Heap Leached Low Grade Ores at Two Nevada Properties. Eng. and Min. J., v. 178, No. 7, 1977, pp. 65-69.

15. Engineering and Mining Journal. Heap Leaching Revives Montana Gold District. V. 182, No. 1, 1981, pp. 90-91.

16. _____. Pelletizing Aids Tombstone Leaching Operation. V. 182, No. 1, 1981, pp. 94-95.

17. Escapule, C. B., L. W. Escapule, C. B. Escapule, and D. D. Rabb. Heap Leaching and Silver Recovery at the State of Maine. Ch. 19 in Interfacing Technologies in Solution Mining, ed. by W. J. Schlitt and J. B. Hiskey (Proc. SME-SPE Int. Solution Mining Symp.) Soc. AIME, Littleton, CO, 1982, pp. 223-230.

18. Eveleth, R. W. Eberle Mine: A Heap Leaching Case History. Min. Eng., v. 31, No. 2, 1979, pp. 138-140.

19. Hedley, N., and T. Howard. Chemistry of Cyanidation. American Cyanimide Co., Wayne, NJ, 1968, 54 pp.

20. Heinen, H. J., D. G. Peterson, and R. E. Lindstrom. Gold Desorption From Activated Carbon With Alkaline Alcohol Solutions. Ch. 33 in World Mining and Metals Technology, ed. by A. Weiss (Proc. Joint Min. and Metall. Inst. of Japan-AIME, Meeting, Denver, CO, Sept. 1-3, 1976). AIME, New York, 1976, pp. 551-564.

21. Heinen, H. J., D. G. Peterson, and R. E. Lindstrom. Processing Gold Ores Using Heap Leach-Carbon Adsorption Methods. BuMines IC 8770, 1978, 21 pp.

22. Hickson, R. J. Heap Leaching Practices at Ortiz Gold Mine, Santa Fe County, New Mexico. Ch. 18 in Interfacing Technologies in Solution Mining, ed. by W. J. Schlitt and J. B. Hiskey (Proc. SME-SPE Int. Solution Mining Symp., Denver, CO, Nov. 18-20, 1981). Soc. Min. Eng. AIME, Littleton, CO, pp. 209-222.

23. Lankenau, A. W., and J. L. Lake (assigned to Hazen Research, Inc., Golden, CO). Process for Heap Leaching Ores. U.S. Pat. 3,777,004, Dec. 4, 1973.

24. Leaver, E. S., J. A. Woolf, and N. K. Karchmer. Oxygen as an Aid in the Dissolution of Silver by Cyanide From Various Silver Minerals. BuMines RI 3064, 1931, 15 pp.

25. Lefler, C. A. Leaching Practices at Smoky Valley Mine. Ch. 6 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 51-56.

26. McClelland, G. E., and J. A. Eisele. Improvements in Heap Leaching To Recover Silver and Gold From Low-Grade Resources. BuMines RI 8612, 1982, 26 pp.

27. McClelland, G. E., and S. D. Hill. Heap Leaching Gold-Silver Ores With Poor Percolation Characteristics. Ch. 5 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Previous Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng., Littleton, CO, 1981, pp. 43-50.

28. McClelland, G. E., D. L. Pool, and J. A. Eisele. Agglomeration - Heap Leaching Operations in the Precious Metals Industry. BuMines IC 8945, 1983, 16 pp.

29. Mining Record. Colorado Mining Activity Roundup 1978. Jan. 31, 1979, 19 pp.

30. _____. Gold Ray Plans To Begin Leaching Operations by September. Aug. 8, 1979, 1 p.

31. _____. Thunder Mountain Gold Makes Agreement To Explore Claims. Oct. 25, 1978, 1 p.

32. _____. Yellow Gold Signs Mineral Properties Agreement. Nov. 25, 1981, 1 p.

33. Nichols, I. L., H. B. Salisbury, and B. K. Shibler. Laboratory Evaluation of Some Factors in Cyaniding Gold Placers. BuMines RI 7559, 1971, 12 pp.

34. Nordhausen, E. A. The Status of Permitting Regulations as Affecting Hydrometallurgy Industry. Pres. at Arizona Conference of AIME Annual Meeting, Tucson, AZ, Dec. 8, 1980; reprinted in Skillings' Min. Rev., v. 70, No. 4, 1981, pp. 10-12.

35. Pizzaro, R. J., D. M. McBeth, and G. M. Potter. Heap Leaching Practice at the Carlin Gold Mining Co., Carlin, NV. Ch. 19 in Solution Mining Symposium, ed. by F. F. Aplan, W. A. McKinney, and A. D. Pernichele (Mini Symp. SME-AIME Annu. Meeting, Dallas, TX, Feb. 25-27, 1974). AIME, 1974, pp. 253-267.

36. Potter, G. M., C. K. Chase, and P. G. Chamberlain. Feasibility of In Situ Leaching of Metallic Ores Other Than Copper and Uranium. Ch. 11 in Interfacing Technologies in Solution Mining, ed. by W. J. Schlitt and J. B. Hiskey (Proc. SME-SPE Int. Solution Mining Symp., Denver, CO, Nov. 18-20, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1982, pp. 123-130.

37. Potter, G. M., and H. B. Salisbury. Innovations in Gold Metallurgy. Min. Cong. J., v. 60, No. 7, 1974, pp. 54-57.

38. Scheiner, B. J., D. L. Pool, J. J. Sjoberg, and R. E. Lindstrom. Extraction of Silver From Refractory Ores. BuMines RI 7736, 1973, 11 pp.

39. Skillings, D. N., Jr. Pinson Mining Co. Marking First Full Year Production. Skillings' Min. Rev., v. 71, No. 28, 1982, pp. 8-10.

40. Smith, M. E. Pilot Scale Heap Leaching at the Pinson Mine, Humboldt County, Nevada. Pres. at SME-AIME Fall Meeting and Exhibit, Salt Lake City, UT, Oct. 19-21, 1983. SME Preprint 83-403, 11 pp.

41. White, L. Heap Leaching Will Produce 85,000 Oz/Year of Doré Bullion for Smoky Valley Mining. Eng. and Min. J., v. 178, No. 7, 1977, pp. 70-72.

42. Zadra, J. B. A Process for the Recovery of Gold From Activated Carbon by Leaching and Electrolysis. BuMines RI 4672, 1950, 47 pp.

43. Zadra, J. B., A. L. Engel, and H. J. Heinen. Process for Recovering Gold and Silver From Activated Carbon by Leaching and Electrolysis. BuMines RI 4843, 1952, 32 pp.

APPENDIX.--GOLD AND SILVER LEACHING BIBLIOGRAPHY

Addison, R., and H. R. Prieto. Reagent Optimization in a Gold-Silver Cyanide Plant. Min. Cong. J., v. 65, No. 1, 1979, pp. 29-33, 65.

American Institute of Mining, Metallurgical, and Petroleum Engineers, Oregon Section. Fifth Gold and Money Session and Gold Technical Session. Proc. 1975 Pacific Northwest Metals and Miner. Conf., Portland, OR, Apr. 6-9, 1975, 201 pp.

_____. Sixth Gold and Money Session and Gold Technical Session. Proc. 1978 Pacific Northwest Metals and Miner. Conf., Portland, OR, May 15-17, 1978, 145 pp.

American Metal Climax, Inc. Recovery of Silver From Electrolytic Copper Refinery Slimes. U.S. Pat. 3,658,510, Apr. 25, 1972; British Pat. 1,343,638, Jan. 16, 1974.

Anderson, S. J. (assigned to Chemsep Corp.). Method of Preparing Ores of Copper, Zinc, Gold, Silver, Platinum or Other Non-Ferrous Metals for Subsequent Leaching or Other Hydrometallurgical Processing. U.S. Pat. 3,958,985, May 25, 1976.

Anderson, T. N., J. C. Parr, L. C. Stone, and D. Metcalf. Gold and Silver Assay Methods in the Mining and Metallurgy Industry. Ch. 12 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 109-120.

Barasky, G., S. J. Swainson, and N. Hedley. Dissolution of Gold and Silver in Cyanide Solutions. Trans. AIME, v. 112, 1934, pp. 660-677.

Beard, R. C., and S. Rivett. Potential for Small Gold Mining Operations in the Kenora, Ont. Area. Can. Min. J., v. 101, No. 9, 1980, pp. 57-58, 61.

Bhappu, R. B., and F. M. Lewis. Gold Extraction From Low Grade Ores--Economic Evaluation of Processes. Min. Cong. J., v. 61, No. 1, 1975, pp. 38-41.

Bhappu, R. B., M. F. Lewis, and J. A. McAllister. Leaching of Low Grade Gold Ores. Economic Evaluation of Available Processes. Preprints, Soc. Min. Eng. AIME, Preprint 74-AS-55, 1974, 18 pp.; abstr. in ch. 18 of Solution Mining Symposium 1974, ed. by F. F. Arlan, W. A. McKinney, and A. D. Permichele (Mining Symp. AIME Annu. Meeting, Dallas, TX, Feb. 25-27, 1974), AIME, 1974.

Bruce, R. (assigned to Canadian Minister of Mines and Technical Surveys). The Preparation of Sulfides, High Antimony Gold Ores for Cyanidation. U.S. Pat. 3,174,848, Mar. 23, 1965.

Buggs, A. A., N. F. Kember, and R. A. Wells (assigned to National Research Development Corp.). Process for the Recovery of Gold and Silver Values From Gold and Silver Bearing Aqueous Cyanide Liquors and Ion Exchange Resin Employed Therein. U.S. Pat. 3,317,313, May 2, 1967.

Caldon, F. (assigned to Sunshine Mining Co.). Acidic Pressure Leaching of Sulphide and Oxide Ores of Silver or Copper. U.S. Pat. 4,084,961, Apr. 18, 1978.

Chadwick, J. R. ERGO - Gold Tailings Reclamation and Retreatment. World Min., v. 33, No. 6, 1980, pp. 48-52.

Chamberlain, C., J. Newton, and D. Clifton. How Cyanidation Can Treat Copper Ores. Eng. and Min. J., v. 170, No. 10, 1969, pp. 90-91.

Chamberlain, P. G., and M. G. Pojar. The Status of Gold and Silver Leaching Operations in the United States. Ch. 1 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 1-16.

Chamberlin, P. D. Heap Leaching and Pilot Testing of Gold and Silver Ores. Min. Cong. J., v. 67, No. 4, 1981, pp. 47-52.

Chase, C. K. Treatment of Manganiferous Silver Ores for Recovery of Silver in View of Changed Precious Metal Economics. Ch. 3 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 23-24.

Chase, C. K., W. S. Ransom, and D. L. Simpson. The Glitter Gets Better - the Two Year Record of Gold Heap Leaching at Smokey Valley Mining Div. - Copper Range Co., Round Mountain, Nevada. Pres. at 109th Annu. Meeting, TMS, AIME, Las Vegas, NV, Feb. 24-28, 1980, preprint A80.3, 8 pp.

Chen, T. P. (assigned to Cyprus Metallurgical Processes Corp.). Acid Leaching of Copper, Gold, Silver, Platinum, Zinc, Lead, Cadmium, Mercury, Tin, Cobalt, Nickel, Antimony, Bismuth or Other Metal. U.S. Pat. 3,930,969, Jan. 6, 1976.

Chisholm, E. O. Canadians Operating Gold Leaching Operation in New Mexico. The Northern Miner, v. 61, No. 27, 1975, pp. 59-60.

Cho, E. H., and C. H. Pitt. Adsorption of Silver Cyanide on Activated Charcoal. Metall. Trans. B, v. 10B, No. 2, 1979, pp. 159-164.

Cho, E. H., and C. H. Pitt. Kinetics and Thermodynamics of Silver Cyanide Adsorption on Activated Charcoal. Metall. Trans. B., v. 10B, No. 2, 1979, pp. 165-169.

Davidoff, C. Extraction of Silver From Silver Ore Cyanide Leach Solutions. U.S. Pat. 3,311,468, Mar. 28, 1967; British Pat. 1,079,615, Aug. 16, 1967.

Deitz, G. A., and J. Halpern. Reaction of Silver With Aqueous Solutions of Cyanide and Oxygen. J. Metals, v. 5, No. 9, 1953, pp. 1109-1116.

de Lucio, F., and M. Vargas. Silver Recovery Increased From 70 to 86 Percent. World Min., v. 32, No. 6, 1979, pp. 60-61.

De Mull, T. J., and R. A. Womack. Heap Leaching Practice at Alligator Ridge. Pres. at SME-AIME Fall Meeting and Exhibit, Salt Lake City, UT, Oct. 19-21, 1983. SME Preprint 83-403, 11 pp.

Dietz, G., Jr., and R. M. Skomoroski (assigned to American Chemical and Refining Co.). Aluminum Containing Precipitation Agent for Precious Metals and Method for Its Use. U.S. Pat. 4,092,154, May 30, 1978.

Dorr, J. V. N., and F. L. Bosqui. Cyanidation and Concentration of Gold and Silver Ores. McGraw-Hill, 2d ed., 1950, 511 pp.

Douglas, H. The Economics of Silver and the Miner. Ch. 14 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 131-136.

Duncan, D. M. Open Pit Gold Mining at Cortez. Colorado Mining Association 1974 Mining Yearbook, Denver, CO, 1974, pp. 92-94.

Duncan, D. M., and T. J. Smolik. How Cortez Gold Mines Heap-Leached Low Grade Gold Ores at Two Nevada Properties. Eng. and Min. J., v. 178, 1977, No. 7, pp. 65-69.

Duncan, D. W., C. C. Walden, and P. C. Trussell (assigned to British Columbia Research Council). Accelerated Method for Bacterial Leaching of Copper, Zinc, Nickel, Molybdenum, Gold, Silver, Cobalt, Cadmium, Tin, and Other Metal Values From Sulfide Ores Thereof. U.S. Pat. 3,305,353, Feb. 21, 1967; Can. Pat. 757,602, Apr. 25, 1967.

Engel, A. L., and H. J. Heinen. Leach-Precipitation-Flotation Tests of a California Copper-Gold Ore. BuMines RI 5342, 1957, 9 pp.

Engineering and Mining Journal. Carlin Gold Mining Will Develop Its Maggie Creek Deposits. V. 181, No. 10, 1980, pp. 55, 121.

_____. Gold and Silver: A Mix of Old and New Technology. V. 176, No. 6, 1975, pp. 107-108.

_____. High Gold Prices Spur Frantic Exploration. V. 181, No. 10, 1980, pp. 29, 31, 150.

_____. Remining Gold: Heap Leaching Planned for Aged Nevada Dumps. V. 180, No. 9, 1979, pp. 270, 272.

_____. Silver and Gold: Heap Leaching Exploits Low Grade Feed. V. 176, No. 6, 1975, pp. 142, 163.

_____. Two Joint Ventures Probe Mining of Microscopic Gold. V. 180, No. 10, 1979, p. 67.

Escapule, C. B., L. W. Escapule, C. B. Escapule, and D. D. Rabb. Heap Leaching and Silver Recovery at the State of Maine. Ch. 19 in Interfacing Technologies in Solution Mining, ed. by W. J. Schlitt and J. B. Hiskey (Proc. SME-SPE Int. Solution Mining Symp., Denver, CO, Nov. 19-20, 1981). Soc. Min. Eng. AIME, Littleton, CO, Nov. 18-20, 1981, SME preprint 81-341.

Eveleth, R. W. Eberle Mine: A Heap Leaching Case History. Min. Eng., v. 31, No. 2, 1979, pp. 138-140.

Fields, R. Cyanide Processing Requires Stringent Precautions. Mine Safety and Health, v. 4, No. 4, 1979, pp. 27-28.

Garrels, R. M., and C. L. Christ. Solutions, Minerals, and Equilibria. Harper, 1965, 450 pp.

Gosser, L. W. (assigned to E. I. du Pont de Nemours and Co.). Concentration of Dilute Aqueous Cyanide Solutions of Gold, Silver and Copper, To Obtain a Solution Sufficiently Rich for Economic Electrolysis for Precipitation With Amalgamated Zinc. U.S. Pat. 3,816,587, June 11, 1974.

Guay, W. J. How Carlin Treats Gold Ores by Double Oxidation. World Min., v. 33, No. 3, 1980, pp. 47-49.

_____ (assigned to Newmont Exploration, Ltd.). Method of Pre-treating Organic Carbon-Containing Sedimentary Gold Ore To Improve Its Amenability to Conventional Cyanidation Treatment. U.S. Pat. 3,846,124, Nov. 5, 1974.

_____. The Treatment of Refractory Gold Ores Containing Carbonaceous Material and Sulfides. Ch. 2 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 17-22.

Guay, W. J., and D. G. Peterson. Recovery of Gold From Carbonaceous Ores at Carlin, Nevada. Trans. Soc. Min. Eng. AIME, v. 254, No. 1, 1973, pp. 102-104.

Hall, K. B. Homestake Uses Carbon-In-Pulp To Recover Gold From Slimes. World Min., v. 27, No. 12, 1974, pp. 44-49.

Halpern, J. Some Aspects of the Physical Chemistry of Hydrometallurgy. J. Metals, v. 9, No. 2, 1957, pp. 280-289.

Hansen, S. M., and D. F. Snoeberger (assigned to U.S. Atomic Energy Commission). Gold Recovery Process. U.S. Pat. 3,545,964, Dec. 8, 1970; Can. Pat. 856,166, Nov. 17, 1970.

Haver, F. P., and M. M. Wong. Ferric Chloride-Brine Leaching of Galena Concentrate. BuMines RI 8105, 1976, 17 pp.

Hedley, N., and T. Howard. Chemistry of Cyanidation. American Cyanamid Co., Wayne, NJ, 1968, 54 pp.; available from American Cyanamid Co., Ind. Chemicals and Plastics Div., Min. Chemicals Dept., Wayne, NJ, 07470.

Hedley, N., and H. Tabachnick. Cyanamid Wants You To Know: ...About the Chemistry of Cyanidation. Part II of Cyanamid Company Report, Article 23, December 1968, pp. 21-72; available from American Cyanamid Co., Ind. Chemicals and Plastics Div., Min. Chemicals Dept., Wayne, NJ, 07470.

Heinen, H. J., J. A. Eisele, D. H. Baker, Jr., and B. J. Scheiner (assigned to U.S. Dep. Interior). Carbanion Leaching of Heavy Metal Ores. U.S. Pat. 3,542,540, Nov. 24, 1970.

Heinen, H. J., G. E. McClelland, and R. E. Lindstrom. Enhancing Percolation Rates in Heap Leaching of Gold and Silver Ores. BuMines RI 8388, 1979, 24 pp.

_____. Enhancing Percolation Rates in Heap Leaching of Gold-Silver Ores. Proc. Pacific Northwest Metals and Minerals Conf., Portland, OR, May 15-18, 1978, 15 pp.

_____. Leaching Agglomerated Gold-Silver Ores. U.S. Pats. 4,256,705, and 4,256,706, Mar. 17, 1981.

Heinen, H. J., D. G. Peterson, and R. E. Lindstrom. Gold Desorption From Activated Carbon With Alkaline Alcohol Solutions. Ch. 33 in World Mining and Metals Technology, ed. by A. Weiss (Proc. Joint Min. and Metall. Inst. of Japan-AIME Meeting, Denver, CO, Sept. 1-3, 1976). AIME, New York, 1976, pp. 551-564.

Heinen, H. J., D. G. Peterson, and R. E. Lindstrom. Processing Gold Ores Using Heap Leach-Carbon Adsorption Methods. BuMines IC 8770, 1978, 21 pp.

_____. Separate Recovery of Silver and Gold From Cyanide Solutions. U.S. Pat. 4,072,587, Feb. 7, 1978.

_____. Silver Extraction from Marginal Resources. Pres. at the 104th TMS-AIME Annu. Meeting, New York, Feb. 16-20, 1975, 14 pp.; copy available from authors at Bureau of Mines, Reno Metallurgy Research Center, 1605 Evans Ave., Reno, NV 89502.

Heinen, H. J., and B. Porter. Experimental Leaching of Gold From Mine Waste. BuMines RI 7250, 1969, 5 pp.

Hickson, R. J. Heap Leaching Practices at Ortiz Gold Mine, Santa Fe County, New Mexico. Ch. 18 in Interfacing Technologies in Solution Mining, ed. by W. J. Schlitt and J. B. Hiskey (Proc. SME-SPE Int. Solution Mining Symp., Denver, CO, Nov. 18-20, 1981). Soc. Min. Eng. AIME, Littleton, CO, pp. 209-222.

Hiskey, J. B. Thiourea as a Lixiviant for Gold and Silver. Ch. 10 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 83-92.

Hoffmann, J. E., and R. G. Ernst (assigned to American Metal Climax, Inc.). Recovery of Silver From Electrolytic Copper Refinery Slimes. U.S. Pat. 3,658,510, Apr. 25, 1975; Can. Pat. 928,966, June 26, 1973.

Hussey, S. J., H. B. Salisbury, and G. M. Potter. Carbon-In-Pulp Silver Adsorption From Cyanide Leach Slurries of a Silver Ore. BuMines RI 8268, 1978, 22 pp.

_____. Carbon-In-Pulp Gold Adsorption From Cyanide Leach Slurries. BuMines RI 8368, 1979, 26 pp.

Hutson, R. J. Exploration Models for Gold in the Archean. Can. Min. J., v. 101, No. 4, 1980, pp. 66-67.

Jacobs, A. L. Chemical Gold Mining. U.S. Pat. 3,545,965, Dec. 8, 1970; Can. Pat. 884,802, Nov. 2, 1971.

Johnson, P. H. Autoclave Leaching of Sulfide Ores of Gold, Copper, Zinc, or Beryllium. Can. Pat. 756,535, Apr. 11, 1967.

_____ (assigned to Howard E. Johnson and Associates). Hydro-Metallurgical Method and Apparatus. U.S. Pat. 3,264,099, Aug. 2, 1966.

_____. Unitized, Portable Flotation-Leach Plants for Treating Partially Gold and Silver Ores. Ch. 7 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 57-64.

Joralemon, P. A Major Gold Belt Takes Shape in Nevada. Min. Eng., v. 30, No. 7, 1978, pp. 759-762.

Kappes, D. W. Heap Leaching Is Small Miners Golden Opportunity. Min. Eng., v. 31, No. 2, 1979, pp. 136-138.

_____. Scaleup Experience in Gold-Silver Heap Leaching. Ch. 4 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 35-42.

Kirby, R. C., and J. A. Barclay. Extraction Processes for Low Grade Ores. Min. Eng., v. 27, No. 6, 1975, pp. 42-47.

Kudryk, V., and H. H. Kellogg. Mechanism and Rate-Controlling Factors in the Dissolution of Gold in Cyanide Solution. J. Metals, v. 6, No. 5, 1954, pp. 541-548.

Kunter, R. S. New Developments at Homestake's Bulldog Mountain Carbon-In-Pulp Silver Plant. Ch. 20 in Interfacing Technologies in Solution Mining, ed. by W. J. Schlitt and J. B. Hiskey (Proc. SME-SPE Int. Solution Mining Symp., Denver, CO, Nov. 18-20, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1982, pp. 231-240.

Law, S. L., and T. E. Green. Analysis of Large Samples of Low Grade Gold Ores by Methyl Isobutyl Ketone Extraction and Atomic Adsorption. BuMines TPR 7, August 1968, 7 pp.

Laxen, P. A. Some Developments in Gold Extraction From Witwatersrand Ores. TMS Paper A75-56, 1975, 16 pp.

Leaver, E. S., J. A. Woolf, and N. K. Karchmer. Oxygen as an Aid in the Dissolution of Silver by Cyanide From Various Silver Minerals. BuMines RI 3064, 1931, 15 pp.

Lefler, C. A. Leaching Practices at Smoky Valley Mine. Ch. 6 in Gold and Silver Leaching, Recovery and Economics, ed., by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 51-56.

Lewis, F. M., C. K. Chase, and R. B. Bhappu. Economic Evaluation of In Situ Extraction for Copper, Gold, and Uranium. Paper in World Mining and Metals Technology, ed. by A. Weiss (Proc. Joint Meeting Min. and Metall. Inst. of Japan and AIME, Denver, CO, Sept. 1-3, 1976). AIME, New York, 1976, pp. 333-348.

Lightner, F. H., R. L. Faverity, and W. E. Coughlin. Borealis Project: A Fast-Track Approach to Mine Development. Min. Eng. (NY), v. 35, No. 11, 1983, pp. 1564-1565.

Lloyd, J. D. Maximizing the Recovery of Gold From Witwatersrand Ores. Miner. Sci. and Eng., v. 10, No. 3, 1978, pp. 208-221.

Loven, A. W. Perspectives on Carbon Regeneration. Chem. Eng. Prog., v. 69, No. 11, 1973, pp. 56-62.

Mathre, O. B., and F. W. DeVries. Destruction of Cyanide in Gold and Silver Mine Process Water. Ch. 9 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 77-82.

Mayling, A. A. (assigned to Bio Metals Corp., Ltd., N.p.l.). Cyclic Process for Leaching Ores of Gold, Silver, Lead, Zinc, Copper, Chromium, Molybdenum or Other Metals. U.S. Pat. 3,347.661, Oct. 17, 1967.

_____ (assigned to Roan Selection, Ltd.). Method for the Bacterial Leaching of Alkaline Sulfide Ores of Copper, Zinc, Lead or Silver. U.S. Pat. 3,455,679, July 15, 1969,; Can. Pat. 812,715, May 13, 1969.

McClelland, G. E., and J. A. Eisele. Improvements in Heap Leaching To Recover Silver and Gold From Low-Grade Resources. BuMines RI 8612, 1982, 26 pp.

McClelland, G. E., and S. D. Hill. Heap Leaching Gold-Silver Ores With Poor Perolation Characteristics. Ch. 5 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 43-50.

McQuiston, F. W., Jr., and R. W. Hernlund. Newmont's Carlin Gold Project. Min. Cong. J., v. 51, No. 11, 1965, pp. 26-29, 32, 38-39.

McQuiston, F. W., Jr., and R. S. Shoemaker. Gold and Silver Cyanidation Plant Practice. AIME, 1975, 187 pp.

_____. Free Milling Ores. Ch. in Gold and Silver Cyanidation Plant Practice. AIME, 1975, 187 pp.

Mechanical Engineering. Improving Gold Extraction. V. 98, No. 10, 1976, p. 58.

Merwin, R. W. Gold Resources in the Oxidized Ores and Carbonaceous Material in the Sedimentary Beds of Northwestern Nevada. BuMines TPR 1, 1968, 16 pp.

Merwin, R. W., G. M. Potter, and H. J. Heinen. Heap Leaching of Gold Ores in Northwestern Nevada. Pres. at AIME Annu. Meeting, Washington, DC, Feb. 16-20, 1969, SME Preprint 69-AS-79, 15 pp.

Nevada Mining Association. Carbonaceous Gold Ore Research Leads to Mercury Leaching Process. Nevada Mining Association News Letter, No. 200, Nov. 15, 1969, 1 p.

Nichols, I. L., and L. Peterson. Leaching Gold-Bearing Mill Tailings From Mercur, Utah. BuMines RI 7395, 1970, 10 pp.

Nichols, I. L., H. B. Salisbury, and B. K. Shibler. Laboratory Evaluation of Some Factors in Cyaniding Gold Placers. BuMines RI 7559, 1971, 12 pp.

Norris, R. P. The Use of Peroxygen Chemicals in the Heap Leaching of Gold and Silver Ores. Pres. AIME Annu. Meeting, Atlanta, GA, Mar. 6-10, 1983. Soc. Min. Eng. AIME preprint 83-26, 8 pp.

Pay Dirt, Intermountain Edition (Bisbee, AZ). Alligator Ridge Gold Mine in Nevada To Begin Production During September. No. 10, July 1980, p. 6.

Payne, A. New South African Complex Leaches Gold, Uranium, and Sulphur From Slimes. Eng. and Min. J., v. 179, No. 1, 1978, pp. 81-84.

Petty, J. W. Method for Recovering Gold, Silver, and Platinum From Oil Shale. U.S. Pat. 3,383,201, May 14, 1968.

Pittie, W. H., G. Overbeek, and K. Doig (assigned to Swarsab Mining, Exploration and Development Co. (PTY), Ltd.). Method of Leaching With Aqua Regia a Mixture of Gold and Rhodium, Iridium, and Ruthenium-i.e., Platinum Group Metals (PGMs). U.S. Pat. 3,920,790, Nov. 18, 1975; Can. Pat. 999,510, June 8, 1976; British Pat. 1,418,060, Dec. 17, 1975.

_____ (assigned to Swarsab Mining, Exploration and Development Co. (PTY), Ltd.). Separation of Gold From Platinum Group Metals (PGMs) Occurring Together in Matte Leach Residue or Sludge. U.S. Pat. 3,929,469, Dec. 30, 1975; Can. Pat. 998,533, Oct. 19, 1976.

Pizarro, R. S., and F. V. Antonio. The Carbon-In-Pulp Plant of the Masbate Gold Operations, Philippines. Ch. 8 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Annu. Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 65-76.

Pizarro, R. S., J. D. McBeth, and G. M. Potter. Heap Leaching Practice at the Carlin Gold Mining Co., Carlin, Nev. Ch. 19 in Solution Mining Symp., ed. by F. F. Aplan, W. A. McKinney, and A. D. Pernichele (Mini Symp. SME-AIME Annu. Meeting, Dallas, TX, Feb. 25-27, 1974). AIME, 1974, pp. 253-267.

Poole, J. L. Review of the Gold and Silver Markets. Paper in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. 110th AIME Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 121-130.

Posel, J. G. (assigned to International Ore Technology, Inc.). Acid Leaching of Ferruginous Sulfide Ores of Copper, Silver, Nickel, Cobalt, and Zinc. U.S. Pat. 3,965,239, June 22, 1976; Can. Pat. 992,749, July 13, 1976.

Potter, G. M. Recovering Gold From Stripping Waste and Ore by Percolation Cyanide Leaching. BuMines TPR 20, 1969, 5 pp.

Potter, G. M., C. K. Chase, and P. G. Chamberlain. Feasibility of In Situ Leaching of Metallic Ores Other Than Copper and Uranium. Ch. 11 in Interfacing Technologies in Solution Mining, ed. by W. J. Schlitt and J. B. Hiskey (Proc. SME-SPE Int. Solution Mining Symp., Denver, CO, Nov. 18-20, 1981). Soc. Min. Eng., AIME, Littleton, CO, 1982, pp. 123-130.

Potter, G. M., and H. B. Salisbury. Innovations in Gold Metallurgy. Min. Cong. J., v. 60, No. 7, 1974, pp. 54-57.

_____. Innovations in Gold Metallurgy. Pres. at Am. Min. Cong. Miner. Convention/Environmental Show, Denver, CO, Sept. 9-12, 1973, 11 pp.; available from Bureau of Mines Salt Lake City Research Center, Salt Lake City, UT.

Pyper, R. A., and J. L. Hendrix. Extraction of Gold from a Carlin-Type Ore Using Thiourea. Ch. 11 in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. SME Sessions on Solution Mining and Economics of Precious Metals, AIME Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, pp. 93-108.

Queneau, P. B., and J. D. Prater (assigned to Kennecott Copper Corp.). Nitric Acid Leaching of a Sulfide Ore of Copper, Nickel, Cobalt or Silver. U.S. Pat. 3,793,429, Feb. 19, 1974.

_____ (assigned to Kennecott Copper Corp.). Nitric Acid Process for Recovering Metal Values From Chalcopyrite or Other Copper Sulfide Ore or a Sulfide Ore of Nickel, Cobalt, or Silver. Can. Pat. 995,468, Aug. 24, 1976.

Regan, R. J. Everyone's in Gold Act, Including the Miners. Iron Age, v. 223, Mar. 3, 1980, pp. 39-40.

Roper, E. C. Pegasus' Gold Ltd. Gold/Silver Operation At Zortman, Montana. Pres. at SME-AIME Fall Meeting and Exhibit, Salt Lake City, UT, Oct. 19-21, 1983. SME Preprint 83-360, 4 pp.

Ross, J. R. (assigned to U.S. Dep. Interior). Method for Desorbing Gold From Activated Carbon on Which It Has Been Absorbed From a Solution Obtained by Leaching Gold Ore With a Cyanide Solution. U.S. Pat. 3,920,403, Nov. 18, 1975.

Ross, J. R., H. B. Salisbury, and G. M. Potter. Pressure Stripping Gold From Activated Carbon. Pres. at Soc. Min. Eng. AIME Annu. Conf., Chicago, IL, Feb. 26-Mar. 1, 1973, 15 pp.; available from Bureau of Mines Salt Lake City Research Center, Salt Lake City, UT.

Sarnoff, P. Precious Metals Economics. Paper in Gold and Silver Leaching, Recovery and Economics, ed. by W. J. Schlitt, W. C. Larson, and J. B. Hiskey (Proc. 110th AIME Meeting, Chicago, IL, Feb. 22-26, 1981). Soc. Min. Eng. AIME, Littleton, CO, 1981, pp. 137-141.

Scheiner, B. J., and R. E. Lindstrom. Copper and Silver Recovery From a Complex Sulfide Concentrate by Ferrous Chloride-Oxygen Leaching. Pres. at AIME Meeting, Feb. 26, 1978, Preprint 78-B-8, 15 pp.

Scheiner, B. J., R. E. Lindstrom, and T. A. Henrie (assigned to U.S. Dep. Interior)). Recovery of Gold From Carbonaceous Ores. U.S. Pat. 3,639,925, Feb. 8, 1972.

_____. Electrolytic Oxidation of Carbonaceous Ores for Improving Gold Recovery. BuMines TPR 8, 1969, 12 pp.

_____. Investigation of Oxidation Systems for Improving Gold Recovery From Carbonaceous Materials. BuMines TPR 2, 1968, 8 pp.

_____. Processing Refractory Carbonaceous Ores for Gold Recovery. J. Metals, v. 23, March 1971, pp. 37-40.

Scheiner, B. J., D. L. Pool, J. J. Sjoberg, and R. E. Lindstrom. Extraction of Silver From Refractory Ores. BuMines RI 7736, 1973, 11 pp.

Schwab, E. E. Reopening a Cripple Creek Gold Mine. Min. Cong. J., January 1976, pp. 19-24.

Seeton, F. A. Review of Carbon Cyanidation. The Mines Magazine, v. 51, No. 7, 1961, pp. 13-15.

Seidel, D. C. Percolation Leaching. Ch. in Unit Processes in Hydrometallurgy, ed. by M. E. Wadsworth and F. T. Davis. Gordon and Breach, 1964, pp. 114-125.

Sheridan, T. Vancouver Consortium Starts Heap-Leaching Operation at Two Montana Gold Mines. Can. Min. J., v. 101, No. 9, 1980, pp. 69-70.

Skillings' Mining Review. Occidental $119 Million Profit on Silver-Gold Contracts. V. 69, No. 7, Apr. 12, 1980, p. 4.

_____. Smoky Valley Operations at Its Round Mountain Mine in Nevada. V. 68, No. 9, Mar. 3, 1979, pp. 8-9, 16-17.

Smith, M. E. Pilot Scale Heap Leaching at the Pinson Mine, Humboldt County, Nevada. Pres. at SME-AIME Fall Meeting and Exhibit, Salt Lake City, UT, Oct. 19-21, 1983. SME Preprint 83-403, 7 pp.

Smith, P. R., Jr., D. W. Bailey, and R. E. Doane. Trends in Chemical Processing and Hydrometallurgy. Eng. and Min. J., v. 173, No. 6, 1972, pp. 173-177.

Swarsab Mining, Exploration and Development Co., Ltd. Method of Leaching With Aqua Regia a Mixture of Gold and Rhodium, Iridium, and Rutheium--i.e., Platinum Group Metals (PGMs)--From a Matte Leach Residue or Sludge Containing Such Values. U.S. Pat. 3,920,790, Nov. 18, 1978; British Pat. 1,418,060, Dec. 17, 1975.

_____. Separation of Gold From Platinum Group Metals (PGMs) Occuring Together in Matte Leach Residue or Sludge. U.S. Pat. 3,929,469, Dec. 30, 1975; British Pat. 1,434,288, May 5, 1976.

Tuwiner, S. B. (assigned to Treadwell Corp). Recovery of Gold, Silver, Copper, or Zinc From Ores by Leaching. U.S. Pat. 3,357,823, Dec. 12, 1967.

U.S. Bureau of Mines. In Situ Mining Research. Proceedings: Bureau of Mines Technology Transfer Seminar, Denver, Colo., Aug. 5, 1981. BuMines IC 8852, 1981, 107 pp.

van Zyl, D. Construction and Investigation of a Clay Heap Leach Pad. Pres. at SME-AIME Fall Meeting and Exhibit, Salt Lake City, UT, Oct. 19-21, 1983. SME Preprint 83-351, 7 pp.

Wargo, J. G. The Next Exploration Stage for Carlin-Type Gold Deposits. Min. Eng., v. 31, No. 9, 1979, pp. 1321-1323.

White L. Heap Leaching Will Produce 85,000 Oz/Year of Doré Bullion for Smoky Valley Mining. Eng. and Min. J., v. 178, No. 7, 1977, pp. 70-72.

Woods, J. L., and T. A. Pittman (assigned to Elmet, Inc.). Extraction of Gold and/or Silver From Ores Thereof. U.S. Pat. 3,826,723, July 30, 1974.

_____ (assigned to Elmet, Inc.). Extraction of Silver and/or Gold From Ore Thereof. Can. Pat. 994,107, Aug. 3, 1976.

Worthington, J. E., I. T. Kiff, E. M. Jones, and P. E. Chapman. Applications of the Hot Springs or Fumarolic Model in Prospecting for Lode Gold Deposits. Min. Eng., v. 32, No. 1, 1980, pp. 73-79.

Zadra, J. B. A Process for the Recovery of Gold From Activated Carbon by Leaching and Electrolysis. BuMines RI 4672, 1950, 47 pp.

Zadra, J. B., A. L. Engel, and H. J. Heinen. Process for Recovering Gold and Silver From Activated Carbon by Leaching and Electrolysis. BuMines RI 4843, 1952, 32 pp.

☆ U.S. GOVERNMENT PRINTING OFFICE : 1984 O - 435-679

H 214 84

THE LIBRARY OF CONGRESS

THE LIBRARY OF CONGRESS

HECKMAN
BINDERY INC.
NOV 84
N. MANCHESTER,
INDIANA 46962

LIBRARY OF CONGRESS
0 002 955 820 6